Junior College Libra
Long Beach, Californ

Volume XXXV September-October 1940 Number 6

Economic Geology

and the

Bulletin of the Society of Economic Geologists

CONTENTS

Bornite-Klaprotholite Relations at Concepcion del Oro, Mexico ..... *Philip Krieger* 687

Albite and Gold ..... *David Gallagher* 698

Structure and Mineral Zoning of the Pailaviri Section, Potosi, Bolivia .. *David LeCount Evans* 737

The Zinc and Lead Deposits of Shawangunk Mountain, New York .... *Albert Irwin Ingham* 751

State Mineral Survey in Arkansas ..... *George C. Branner* 761

Discussion and Communications:

Nature of the Ore-Forming Fluid: A Discussion .. *Earl Ingerson and George W. Morey* 772

Reviews:

Contributions to a Knowledge of the Lead and Zinc Deposits of the Mississippi Valley Region (ed. Bastin) ..... *W. H. Newhouse* 786

Texas Oil and Gas Since 1543 (Warner) 790

Books Received ..... *David Gallagher* 790

Scientific Notes and News 792

PUBLISHED SEMI-QUARTERLY

Five Dollars a Year, Seventy-five Cents a Copy

THE ECONOMIC GEOLOGY PUBLISHING COMPANY

Prince and Lemon Streets, Lancaster, Pa.

Entered as second-class matter, March 30, 1906, at the Post Office at Lancaster, Pa., under the Act of Congress of March 3, 1879

TECHNOLOGY

Economic Geology

and the

Bulletin of the Society of Economic Geologists

Issued Semi-Quarterly and sent to subscribers on or about the following dates: February 1, March 15, May 1, June 15, August 1, September 15, November 1, December 15.

Manuscripts for publication should be sent to the Editor, **ALAN M. BATEMAN, at Yale University, Yale Station, New Haven, Conn.** It is requested that contributors exercise care in writing *scientific* and *proper names*. References to other publications should be in accordance with the forms used in the pages of this journal. The manuscript should be typewritten with double space lines and must be preceded by *a brief abstract*. Galley proof will be sent authors only where a request to this effect accompanies the manuscript, or when, in the editor's opinion, the subject matter is such as will require correction by the author.

Reviews should conform to the journal usage. Review Committee: The Editor, C. H. Behre, L. C. Graton, J. T. Singewald, Jr., J. Gilluly, A. F. Buddington, W. H. Newhouse.

Books and Pamphlets for review should be sent to the Editor.

Reprints. Contributors desiring reprints of their papers may obtain them by filling out the order slip which will be attached to the galley proof when it is sent to the author. Provided the order slip is received by the editor, *with the return of the proof*, 50 reprints without covers will be furnished without charge. Reprints of discussions and informal communications are not furnished free of charge except when they exceed four pages in length when 50 will be supplied without charge. Reprints of reviews are not supplied. Additional reprints will be furnished at approximately the rates given in the table below when ordered *in advance of publication*. The rates apply only to plain text, with line engravings. Papers containing folded maps or plates will be more expensive.

The following rates *do not* include free carriage. *Postage or express must be paid by the author.*

	4 pp.	8 pp.	12 pp.	16 pp.	20 pp.	24 pp.	28 pp.	32 pp.	Covers
50 copies	$2.15	$3.35	$5.20	$5.40	$7.00	$8.00	$9.20	$9.85	$2.30
100 "	2.55	3.95	6.00	6.60	8.40	9.80	11.40	12.25	3.10
200 "	3.35	5.15	8.00	9.00	11.20	13.40	15.80	17.05	4.75
500 "	5.47	8.35	13.35	15.40	18.63	23.00	27.60	29.90	9.10

Standard covers are of the same style of type and paper as the cover of the journal, and bear the title of the article and name of its author. Special printing on cover is charged for at the cost of composition. Plates are $2.00 for the first 50 if printed on one side, and 1½ cents for additional ones; printed on both sides, $3.00 for the first 50, and 2¼ cents for additional ones.

Single copies of reprints (without covers) of many of the articles published in volumes issued since 1926 (Vol. XXI) are available at the following prices, upon application to the Business Editor, at Urbana, Illinois.

1-4 pp. 15c	5-8 pp. 20c	9-12 pp. 25c	13-20 pp. 30c	21-28 pp. 35c
29-36 pp. 40c	37-44 pp. 45c	45-52 pp. 50c	53-60 pp. 55c	61-68 pp. 60c

If illustrated by plates, add 3c for each plate if printed on one side, and 5c if printed on both sides.

Subscriptions. The price of the journal to subscribers in the United States and its dependencies is 75 cents for a single copy, or $5.00 a year for eight numbers. To subscribers in Canada, Cuba, Mexico, Spain, and countries in Central and South America, except Dutch and French Guiana, the annual rate is $5.30; to other countries, $5.75.

Forwarding. Subscribers wishing their journal to be forwarded to a new address should leave postage for that purpose with the Postmaster at their old address.

Missing numbers will be replaced without charge if claim is made within four weeks after the date of issue of the following number, provided that the neglect to receive them is not due to neglect to arrange for their forwarding.

Remittances should be made payable to the **ECONOMIC GEOLOGY PUBLISHING COMPANY,** and should be mailed to **W. S. BAYLEY,** Business Editor, Urbana, Illinois, to whom also all **Business Communications** should be addressed.

Foreign Agents. Thomas Murby & Co., 1 Fleet Lane, Ludgate Circus, London, E. C. 4, British Agents. The Maruzen-Kabushiki-Kaisha, P. O. Box 605, Tokyo Central, Tokyo, Japan, Agents for the Orient.

Indexed in the Industrial Art Series.

LANCASTER PRESS, INC., LANCASTER, PA.

Junior College Library
Long Beach, California

ECONOMIC GEOLOGY

A SEMI-QUARTERLY JOURNAL

EDITOR: ALAN MARA BATEMAN
Yale University, New Haven, Connecticut

BUSINESS EDITOR: WILLIAM SHIRLEY BAYLEY
University of Illinois, Urbana, Illinois

ASSOCIATE EDITORS

CHARLES KENNETH LEITH
University of Wisconsin, Madison, Wis.

G. F. LOUGHLIN
U. S. Geological Survey, Washington, D. C.

C. N. FENNER
Geophysical Laboratory, Washington, D. C.

B. S. BUTLER
Univ. of Arizona, Tucson, Ariz.

W. E. WRATHER
Dallas, Texas

HEINRICH RIES
Cornell University, Ithaca, N. Y.

OSCAR E. MEINZER
U. S. Geological Survey, Washington, D. C.

PAUL RAMDOHR
Univ. of Berlin, Germany

L. C. GRATON
Harvard University, Cambridge, Mass.

E. C. ANDREWS
Sydney, Australia

E. S. MOORE
University of Toronto, Toronto, Can.

A. I. LEVORSEN
Tulsa, Oklahoma

PER GEIJER
Royal Technical University, Stockholm, Sweden

TAKEO KATO
Imperial University, Tokyo, Japan

ALEX. L. DU TOIT
Johannesburg, South Africa

J. A. DUNN
Geological Survey, Calcutta, India

PUBLISHED BY

THE ECONOMIC GEOLOGY PUBLISHING COMPANY

SOCIETY OF ECONOMIC GEOLOGISTS

THE PUBLICATIONS OF WHICH CONSTITUTE
A PART OF THIS JOURNAL

OFFICERS FOR 1940

G. F. LOUGHLIN.....*President*	J. B. TYRRELL.....*Vice-President*
W. D. JOHNSTON, JR.....*Secretary*	J. T. SINGEWALD, JR.....*Treasurer*
ALAN M. BATEMAN.....*Pres. Elect*	W. J. MEAD.....*Vice-Pres. Elect*

Councilors

1940	*1941*	*1942*
O. E. MEINZER	JAMES GILLULY	J. M. BOUTWELL
F. H. LAHEE	T. B. NOLAN	PAUL BILLINGSLEY
I. B. JORALEMON	PHILIP KRIEGER	L. C. SNIDER

Regional Vice-Presidents

M. K. SHALER.....	Brussels, Belgium.....	*For Europe*
J. A. DUNN.....	Calcutta, India.....	*For Asia*
J. A. BANCROFT.....	Johannesburg, Africa.....	*For Africa*
G. B. LANGFORD.....	Toronto, Canada.....	*For North America*
F. R. KOEBERLIN.....	Santiago, Chile.....	*For South America*
H. J. C. CONNOLLY.....	Melbourne, Australia.....	*For Australia*

Executive Committee

G. F. LOUGHLIN, *Chairman*		W. S. BURBANK
H. D. MISER	T. B. NOLAN	A. W. PINGER

Finance Committee

JAMES T. DUCE, *Chairman*	ARTHUR NOTMAN
S. H. BALL	W. J. MEAD

Program Committee

Q. D. SINGEWALD, *Chairman*	H. E. MCKINSTRY	D. G. THOMPSON

Committee on Publications

B. S. BUTLER, *Chairman*	E. L. DEGOLYER	W. C. MENDENHALL

ECONOMIC GEOLOGY

VOL. XXXV SEPT.-OCT., 1940 No. 6

BORNITE–KLAPROTHOLITE RELATIONS AT CONCEPCION DEL ORO, MEXICO.

PHILIP KRIEGER.

ABSTRACT.

The occurrence of klaprotholite, a copper-bismuth sulphide, in the copper ore of Concepcion del Oro, Mexico, and its relation to bornite is described. It occurs as irregularly-rounded blebs; long, slender blades; short, rod-like forms; small euhedral crystals; and as graphic intergrowths, all of which are found within bornite. The mineral is believed to have formed as a result of unmixing from a solid solution.

Supergene chalcocite veins and selectively replaces bornite. Klaprotholite, however, has resisted replacement to a marked degree.

In view of the rarity of klaprotholite, the material from Concepcion del Oro is of interest because of the variety of forms it assumes, its paragenetic relation to bornite, and the manner in which it illustrates selective replacement of bornite by chalcocite.

INTRODUCTION.

SEVERAL years ago the writer studied a suite of ores from the Concepcion del Oro district, Zacatecas, Mexico, among which was noted an unusual mineral on which positive identification could not be made at the time. The mineral was associated with high-grade copper ore consisting of primary bornite abundantly veined with supergene chalcocite. It was observed only in bornite or in chalcocite where the latter occurred as veins in bornite, and its relations to these minerals was such as to warrant more than ordinary attention. Due to the small size of individual particles of the mineral, however, earlier attempts at identification were inconclusive.

Since then additional material has been secured for study and the mineral identified as klaprotholite, the copper-bismuth sulphide ($3Cu_2S.2Bi_2S_3$). The interesting relation it bears to bornite and the variety of forms which the mineral assumes, as well as the excellent manner in which it illustrates highly selective replacement of bornite by supergene chalcocite, merit description.

Although klaprotholite[1] was described as early as 1868[2] and several references are made to it in connection with the study of ores in polished surfaces,[3] there appears to be no adequate description of its properties and relation to other minerals under the reflecting microscope. The only microscopic data and etch reactions for klaprotholite are those given by Short[4] on a specimen from Butte, Montana, reported to have been identified by Laney, but for which no description as to occurrence or relation to other minerals could be found in the literature.

That the mineral is more common than is generally supposed is shown by the fact that it has been observed in polished surfaces of copper ore from a number of localities,[5] although adequate descriptions of the mineral from these localities are lacking. In addition to the localities cited by Rogers, the writer has observed the same mineral in ores of Redruth, Cornwall, and the Silver Valley mine, North Carolina. It is quite possible that the unknown mineral from Butte, Montana, described by Graton and Murdock[6] in their study of sulphide ores may be klaprotholite, for the description given by them corresponds to the mineral observed in Butte ores by the writer, which is identical to klaprotholite from Concepcion del Oro.

[1] Dana, E. S.: System of Min. 6th ed. "The name klaprothite was given to lazulite by Beudant in 1824, hence the change of Peterson's name to klaprotholite."

[2] Peterson and Sandberger: Jahr. Min., p. 415, 1868.

[3] Rogers, A. F.: The so-called graphic intergrowths of bornite and chalcocite. Econ. Geol., 11: 582–593, 1916. Laney, F. B.: The geology and ore deposits of the Virgilina District of Virginia and North Carolina. Va. Geol. Surv. Bull. 14: 79, 1917.

[4] Short, N. M.: Microscopic determinations of the ore minerals. U. S. Geol. Surv. Bull., 825, 1931.

[5] Rogers, A. F.: *op. cit.*

[6] Graton, L. C., and Murdock, J.: The sulphide ores of copper. A. I. M. E. Trans., 45: 46, 1913.

Gaudin and Dicke[7] have described pyrosynthetic experiments with compounds of copper, arsenic, antimony, and bismuth among which klaprotholite is claimed to have been produced synthetically by fusing a mixture of copper and bismuth with excess sulphur. The unmixing structures obtained by them show considerable resemblance to some of the intergrowths here described.

Properties of Klaprotholite.—Klaprotholite polishes very smoothly and evenly without pitted structure, is free from scratches and resists tarnish to a marked degree. No cleavage was observed in any of the specimens examined. Hardness: B, essentially the same as chalcocite and somewhat softer than bornite as shown by very slight relief when polished on a cloth lap. Color in plain light with blue daylight filter is creamy white with a slight pinkish tinge.

Anisotropism is moderately strong. Polarization colors are grayish brown to creamy pink. No internal reflection.

Etch tests:

Negative—HNO_3 (1:1), HCl (1:1), Aqua Regia, $HgCl_3$, KOH (40 per cent), $FeCl_3$.

Positive—HNO_3 (conc.) stains brown, rubs nearly clean. KCN (40 per cent) tarnishes bluish purple, rubs clean.

OCCURRENCE.

The material studied came from 12 meters below level 9, Manzanillas stope, Aranzazu mine, Concepcion del Oro district, Zacatecas, Mexico. In a hand specimen the ore appears to consist of massive bornite cut by numerous small veins of supergene chalcocite. Polished surfaces, however, show an abundance of klaprotholite distributed rather uniformly through the bornite. It occurs in a variety of forms among which the following are prominent and all of which can usually be observed in a single polished surface.

1. Irregularly rounded grains up to 0.5 mm. in size.

[7] Gaudin, A. M., and Dicke, G.: The pyrosynthesis, microscopic study and iridescent filming of sulphide compounds of copper with arsenic, antimony and bismuth, Part II. ECON. GEOL., 34: 214–232, 1939.

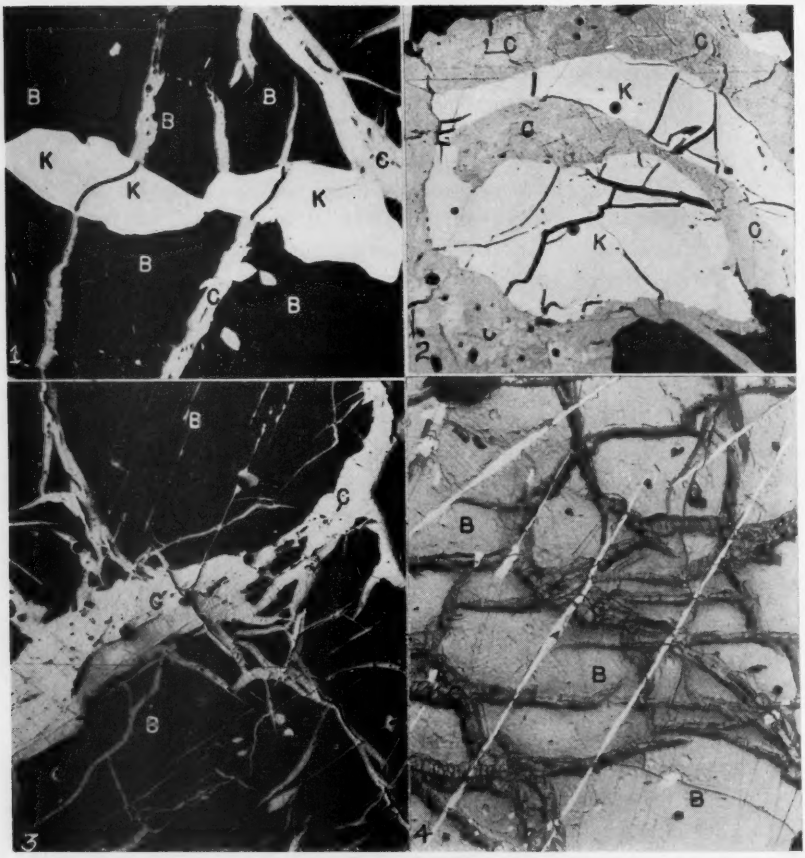


FIG. 1. Larger blebs of klaprotholite (K) in bornite (B), which show selective replacement by supergene chalcocite (C). Note that the fractures containing chalcocite pass through klaprotholite but that the chalcocite stops abruptly at the contact. × 260. Oil immersion.

FIG. 2. Blebs of klaprotholite (K) surrounded by supergene chalcocite (C). Chalcocite has replaced bornite (black) but has not affected klaprotholite, nor has it penetrated along fractures in klaprotholite. × 260. Oil immersion.

2. Long, slender, blade-like crystals up to 1.5 mm. in length, generally oriented along crystallographic directions in bornite.

3. Groups of small, euhedral crystals about 0.05 mm. in size. These generally show a rhombic cross-section and are commonly oriented along crystallographic directions in bornite.

4. Clusters containing innumerable tiny rod-like crystals less than 0.02 mm. in size, often oriented along crystallographic directions in bornite.

5. As graphic intergrowths with bornite.

The largest areas of klaprotholite consist of irregularly rounded, isolated grains that occur more or less uniformly disseminated through the bornite (Figs. 1 and 2). They show no evidence of having replaced bornite or that they have penetrated bornite along fractures or cleavages. Later fractures, however, may cut both bornite and klaprotholite. As shown in some of the photomicrographs, supergene chalcocite replaces bornite along the late fractures but stops abruptly when the contact with klaprotholite is reached, although it may continue along the margin of the klaprotholite or in the fracture on the opposite side of the klaprotholite grain.

One of the more interesting varieties of klaprotholite is the long, slender, blade-like forms that the mineral sometimes assumes (Figs. 3 and 4). These blades may attain a length of 1.5 mm. They commonly pass through several veinlets of supergene chalcocite, thus giving the impression that they are later in age than chalcocite. This effect, however, is due entirely to the fact that the klaprotholite has resisted replacement by chalcocite to a marked degree, whereas bornite has been readily replaced.

FIG. 3. Long, slender rods of klaprotholite, oriented along crystallographic directions in bornite (*B*). The bornite is veined and replaced by supergene chalcocite (*C*) but the klaprotholite rods have not been replaced. × 290. Oil immersion.

FIG. 4. Selective replacement of bornite (*B*) by supergene chalcocite (*C*). Long rods of klaprotholite, although earlier than chalcocite, show little or no replacement by chalcocite. Chalcocite has been etched with dilute nitric acid to bring out greater contrast. × 135. Oil immersion.

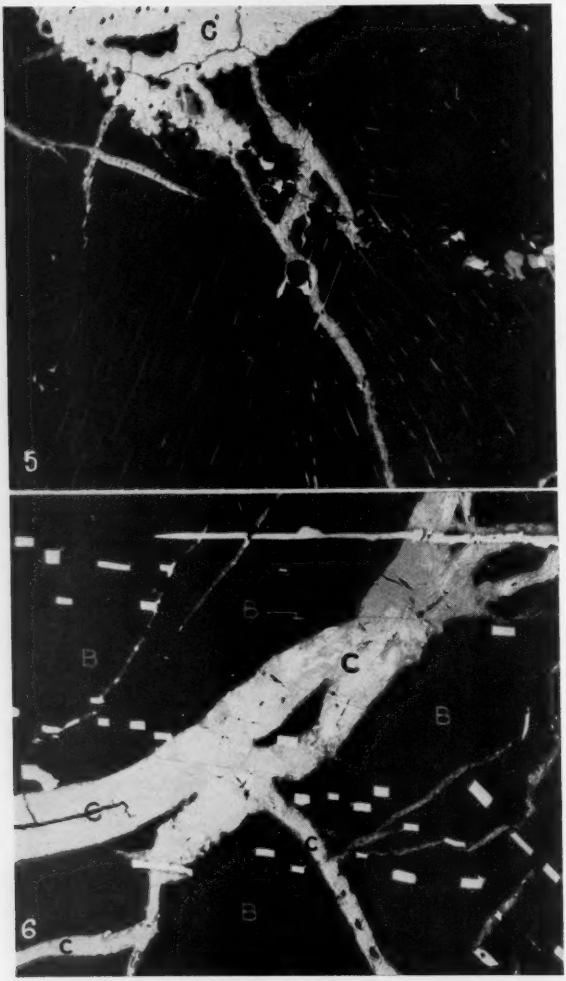


FIG. 5. Small rods of klaprotholite oriented along crystallographic directions in bornite (black), which is veined and replaced by supergene chalcocite (*C*). ×135. Oil immersion.

Such blades commonly occur in parallel groups, generally oriented along crystallographic directions in bornite and in places form a distinct triangular pattern indicative of the isometric structure of bornite. The blades show no evidence of having replaced bornite or of having penetrated along fractures or cleavages in bornite.

A third variety consists of groups of small, stubby, euhedral crystals, generally showing a sharp rhombic cross-section (Fig. 6). These are abundantly distributed throughout the bornite and commonly show parallel orientation. In a few cases such crystal groups form triangular patterns in bornite, indicating that the crystallographic direction of bornite was a controlling factor in their distribution and orientation.

Where veins containing supergene chalcocite pass through areas of bornite containing such crystals, the chalcocite does not replace klaprotholite. Consequently, numerous chalcocite veins show small crystals of klaprotholite within them, still retaining a sharp euhedral form and entirely unaffected by replacement, although bornite all around them may be replaced by chalcocite. This condition shows up in a striking manner when chalcocite is etched with dilute nitric acid.

Areas in bornite were observed to contain innumerable small, closely-spaced, rod-like crystals of klaprotholite (Fig. 9). Although distinct cross-sections are not always apparent, the regularity of the forms suggests that they are tiny euhedral crystals, although smaller and more elongated than those showing good rhombic cross-sections. These also show a distinct parallel orientation among themselves and their distribution is apparently controlled by crystallographic directions of bornite (Fig. 5). These show the same resistance to replacement by chalcocite as other forms of klaprotholite. Chalcocite veins pass through areas containing such crystals and replace bornite but leave klaprotholite crystals unaffected by replacement.

FIG. 6. Small euhedral crystals and a single long rod of klaprotholite in bornite (*B*), both of which pass through veins of supergene chalcocite (*C*). The chalcocite replaces bornite but has not affected the klaprotholite. × 135. Oil immersion.

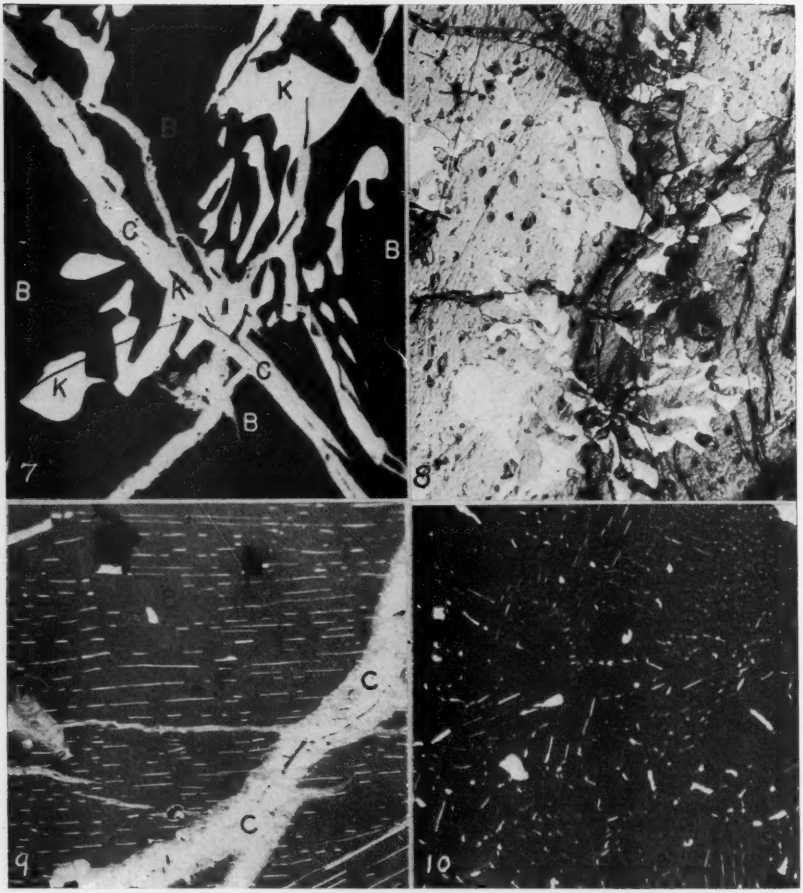


FIG. 7. Graphic intergrowth of bornite (*B*) and klaprotholite (*K*). The area has been veined by supergene chalcocite (*C*) but only bornite is replaced by chalcocite. × 290. Oil immersion.

FIG. 8. A similar graphic intergrowth of bornite (light gray) and klaprotholite (white) etched with dilute nitric acid for greater contrast. Note how klaprotholite has resisted replacement by supergene chalcocite (dark gray). × 290. Oil immersion.

Graphic intergrowths of klaprotholite and bornite are common (Fig. 7). Such intergrowths are generally quite large and the areas of klaprotholite in them are comparable in size to the larger grains of klaprotholite. Where such intergrowths are penetrated by chalcocite veins the klaprotholite is invariably unreplaced, although the bornite with which it is intergrown may be completely replaced. This condition is brought out in a striking manner when the chalcocite is etched with dilute nitric acid (Fig. 8).

Selective Replacement of Bornite by Chalcocite.—One of the most striking features of the ores is the very marked degree to which klaprotholite has resisted replacement by chalcocite. Bornite is cut by numerous veinlets of chalcocite ranging from a fraction of a millimeter in width up to 4 or 5 millimeters. These invariably traverse areas of bornite containing one or more of the several varieties of klaprotholite, but even in those places where large areas of bornite have been replaced by chalcocite, the klaprotholite remains in its original form and shows little or no replacement. The small euhedral crystals of klaprotholite are just as sharply defined in these areas as in bornite, and even the smallest rods or blebs show but little replacement despite the fact that they may be completely surrounded by chalcocite. This resistance to replacement is best illustrated by etching the chalcocite with dilute nitric acid, which brings the klaprotholite out in sharp contrast with etched chalcocite. Long blades, small crystals and rods, the larger rounded areas and graphic intergrowths are all found within chalcocite veins or appear to pass through chalcocite veins.

This selectivity is especially noticeable where replacement veins of chalcocite follow fractures in the ore. The fractures commonly cut both bornite and klaprotholite. Chalcocite, however, where following along such fractures, has replaced bornite readily

FIG. 9. Bornite (black) with numerous small inclusions or rod-like forms of klaprotholite cut by veinlets of supergene chalcocite (*C*). Note that the rods extend into the chalcocite vein and have not been replaced. × 410. Oil immersion.

FIG. 10. Another type of bornite-klaprotholite unmixing structure. Small blebs and rods of klaprotholite show an irregular distribution in bornite (black). × 290. Oil immersion.

and may develop into a fairly wide vein, but where the contact with klaprotholite is reached replacement ceases abruptly. Although the fracture continues through klaprotholite, the chalcocite does not, but may emerge on the opposite side of the klaprotholite grain and replace the bornite around the margins of the klaprotholite. A good illustration of this is shown in Figs. 1 and 2.

In Rogers' description of klaprotholite [8] in the Butte ores, it is stated that some of the graphic intergrowths of bornite and chalcocite are the result of the selective replacement of klaprotholite by chalcocite. The illustrations shown by Rogers are not especially convincing that this has occurred. In view of the ease with which bornite is replaced by chalcocite and the obvious resistance of klaprotholite to replacement by chalcocite, as shown by the present study, it would seem that the conclusions of Rogers are unwarranted unless the conditions of replacement were wholly different from those of the present ore.

ORIGIN.

The question naturally arises as to the origin of the klaprotholite. There can be little doubt that it was deposited from the same hypogene solutions from which the bornite was derived, and all the evidence seems to indicate that they were deposited simultaneously as products of unmixing or exsolution.

Schwartz [9] has admirably reviewed the textures due to unmixing and lists the possible criteria that may be used for determining products of exsolution. Many of the examples show a relation to the crystallographic directions of the host mineral, although examples are also cited where no such relationship is apparent.

One of the more prominent features of the klaprotholite inclusions in bornite is the obvious crystallographic control that bornite has exerted on the larger blade or plate-like forms, small crystals, and tiny rod-like forms. The larger rounded or irregular inclusions of klaprotholite show no such control by bornite, but so far

[8] Rogers, A. F.: *op. cit.*

[9] Schwartz, G. M.: Textures due to unmixing of solid solutions. ECON. GEOL., 26: 739–763, 1931.

as can be observed are distributed more or less at random through the bornite.

The variety of forms that klaprotholite assumes; the well-developed crystal outlines of the smaller inclusions; graphic intergrowths; the fact that all of the klaprotholite observed occurs within bornite, and the control by crystallographic directions of bornite all strongly suggest that the klaprotholite has developed as a result of unmixing or exsolution. There is complete lack of evidence, even when examined under high power, that it has replaced bornite, for it shows no relation whatever to grain boundaries, fractures or continuous penetration of bornite. All contacts between klaprotholite and bornite are sharp and smooth with no ragged contacts as might be expected if due to replacement.

If the structures observed were due to replacement, and a difference in age between bornite and klaprotholite existed, one could reasonably expect to find some of the commonly accepted criteria of replacement or cross-cutting structures, and klaprotholite would not be confined wholly to bornite but should also occur with other metallic constituents or alone in the gangue. It is difficult to see how such a variety of forms could be obtained without any evidence whatever of recognizable replacement effects by any other means than a process of exsolution or unmixing during slow cooling. Such an origin would also be consistent with experimental results obtained by Gaudin and Dicke [10] and with structures of natural substances generally recognized as being due to unmixing.

COLUMBIA UNIVERSITY,
NEW YORK CITY,
April 12, 1940.

[10] Gaudin, A. M., and Dicke, G.: *op. cit.*

ALBITE AND GOLD.

DAVID GALLAGHER.

ABSTRACT.

A search of the literature reveals an imposing number of gold deposits from many parts of the world that are genetically related to albite-rich igneous rocks. The evidence suggests that these deposits contain little silver and the sulphides are simple and not abundant, whereas gold deposits genetically related to potash rich rocks are argentiferous, polymetallic, or contain abundant sulphides. It is concluded also that these gold deposits cannot be explained by a one-magma theory of petrogenesis, and that the granitic and trondhjemitic rock suites with their respective pegmatites and gold deposits were derived from two distinct magma types. Lastly, it is suggested that the nature of the associated feldspars is of sufficient significance to warrant more close attention.

INTRODUCTION.

DESCRIPTIONS of gold deposits have, with increasing frequency of late, indicated a genetic relationship between the gold mineralizing solutions and igneous rocks rich in albite. Several tentative generalizations are suggested by the evidence from the literature presented below.

The author takes pleasure in expressing his gratitude for the award of the Samuel Franklin Emmons Memorial Fellowship, which made possible the study, of which this paper is a portion, and to Yale University for the hospitality and facilities provided. He wishes especially to thank Professor Adolph Knopf for his suggestions and Professor Alan Bateman for his guidance, and critical reading of the manuscript.

CORRELATIONS OF ROCKS AND ORES.

The advisability of studies correlating the facts of ore deposits with the geological data on their environments has been pointed out by S. F. Emmons,[1] Lindgren,[2] and E. Y. Dougherty,[3] among

[1] Emmons, S. F.: Ore Deposits, p. 80. A. I. M. E. "Emmons Volume," 1913.

[2] Lindgren, W.: ECON. GEOL., 23: 596, 1928.

[3] Dougherty, E. Y.: ECON. GEOL., 30: 879, 1935.

others. Of the numerous attempts that have been made, one of the commonest types is a study of the kinds of igneous rocks associated with the kinds of ore deposits.

One of the most widely accepted conclusions that has come out of such studies is that many gold deposits are genetically related to acidic granitic rocks. This idea has been advanced by many, among whom J. E. Spurr was one of the strongest proponents. He emphasized the idea again and again from his early reports on the Yukon [4] through his many papers down to his book "The Ore Magmas." In fact the idea of the acid character has become so well established that the character of the associated feldspars has been slighted, even in some of the more noteworthy, recent papers [5] dealing with this phase of the subject.

Incidental to his geological studies of the Lupa Goldfield the writer found that the gold mineralization was genetically related to an alaskite rich in albite. In order to ascertain if such a relationship was peculiar to this region, or of more general occurrence throughout the World, a search of the literature has been made, and is here presented. It has been found that a genetic relationship between certain gold deposits and albite-rich igneous rocks is a common phenomenon, and in addition the following generalizations have been prompted by the evidence from the literature given below. These are presented in advance to forewarn the reader of the significance to be seen in the data. They are presented more as tentative suggestions to stimulate further attention to the matter than as substantiated conclusions, because the deposits show a wide variety of characters, and the number of cases cited as evidence is small, since precise descriptions of the feldspars are disappointingly rare in the literature.

1. Where gold is the only valuable metal, and other metallic minerals are not abundant, the genetically related igneous rocks are commonly high in albite.

2. Where silver is more abundant, the lime content of the feldspars of the associated igneous rock is higher.

[4] Spurr, J. E.: U. S. Geol. Surv. 18th Ann. Rept. Pt. 3: 87–392, 1898.

[5] Ore Deposits of the Western States, A. I. M. E. "Lindgren Volume," 1933.

3. Where silver is in considerable excess over gold, or where gold is subordinate to other metals, or where other metallic minerals are very abundant, soda feldspars are generally lacking, and not uncommonly the genetically related igneous rocks are notably potassic.

The results of an incomplete, but representative cross-section of the literature follows, in which evidence is offered from the Canadian Shield, Newfoundland, British Columbia and Alaska, California, the American Cordilleran, the Homestake Mine, the Southern Appalachians, Mexico, Central and South America, South Africa, Southern Rhodesia, Tanganyika, the Congo, the Gold Coast, Australia, New Zealand, the Philippines, Malaya, Korea, Russia, Sweden, and England, in support of the above generalizations.

CANADIAN SHIELD.

Tyrrell[6] considers the Algoman of Canada to have been a "Chrysogenetic Epoch" and says that the gold-quartz veins of Canada ". . . are very generally associated with Albite-porphyries." Dougherty, stating the case a little less strongly, says,[7] "It appears to be generally a fact that the more important gold-quartz deposits of the Canadian Shield lie in, next to, or in the general vicinity of intrusives in which quartz and (or), albite (less commonly potash feldspar) are conspicuous or predominant minerals. Commonly these quartz- and albite-bearing intrusives have a porphyritic texture. That there is genetic association of intrusives, particularly porphyries, and gold is firmly believed by the majority of persons connected with mining in the Canadian Shield."

The following mines are described as being genetically related to albitic rocks by E. L. Bruce:[8] Granada, Siscoe, Hollinger, MacIntyre-Porcupine, Vipond, Dome, Ankerite, March, Kirkland Lake, Teck-Hughes, Lake Shore, Wright-Hargreaves, Sylvanite, Tough-Oakes-Burnside, Barry-Hollinger, Argonaut, Wawa Lake,

[6] Tyrrell, J. B.: Trans. Royal Soc. Canada, Ser. III, IX: 117, 1915.

[7] Dougherty, E. Y.: Econ. Geol., 30: 879–889, 1935.

[8] Bruce, E. L.: Mineral Deposits of the Canadian Shield. The Macmillan Co., Toronto, 1933.

Minto, and the mines near Goudreau. This group includes all of the major gold mines of Canada. At the Long Lake Gold Mine, "the gold-bearing solutions are thought to have come from the diorite intrusive. . . ." Doloro, Cordova, Herb Lake, Foley, and the mines of the Red Lake Basin are attributed to somewhat indefinite "granite," and the eleven other gold mines mentioned are not assigned any specific origin.

Bruce [9] has "suggested that the proximity of the ore bodies to exposed masses of igneous rocks is entirely due to structural control and that any intrusives that are directly related to the ore solutions lie deep below the surface." He [10] admits, however, that "for some occurrences, there is evidence suggestive of genetic relationship between the ore bodies and neighbouring intrusive rocks." He [11] contends that it is the fortuitous result of a structurally controlled series of events that brings the ores near to the albitite porphyry bodies at some of the gold deposits between Lake Nipigon and Long Lake, Ontario. His view is that the ore-bearing solutions and the associated visible igneous rocks were derived from a common parental magmatic source at depth, rather than that the ore came directly from the visible rocks.[12] Many geologists agree with this idea, and in fact Spurr [13] strongly emphasized it even for the pyrometasomatic deposits. However, despite a distinct trend in this direction, many geologists still believe that the associated igneous rocks, if not themselves the actual source, are a representative sample of the igneous rock that was the parent of the ore-bringing solutions.

Cooke,[14] by the aid of a diagram, shows the spatial relationship of ore minerals to a porphyry dike on the Stabell claim in Western Quebec. Quartz diminishes gradually in amount to about 600 feet from the dike, and then falls off rapidly, nearly reaching zero

[9] Bruce, E. L.: Econ. Geol., 32: 198–199, 1937.

[10] Bruce, E. L.: A. I. M. E. Tech. Pap. 807: 1, 1937.

[11] Bruce, E. L.: Econ. Geol., 34: 357–368, 1939.

[12] Bruce, E. L.: Mineral Deposits of the Canadian Shield, p. 252. The Macmillan Co, Toronto, 1933.

[13] Spurr, J. E.: A. I. M. E. Trans., 74: 112, 1926.

[14] Cooke, H. C.: Can. Geol. Surv., Summ. Rept., 1923. Pt. CI: 76–125, esp. fig. 14, p. 84.

at 900 feet. Pyrrhotite increases gradually away from the dike, reaching a maximum at about 600 feet which is maintained to 950 feet where it falls suddenly to zero. Chalcopyrite, with which nearly all the gold is associated, is uniform in amount for about 300 feet and then falls gradually to zero at 600 feet. He believes that the orebody, in this case, must have come from a larger body of magma than the dike, and so he concludes that both the dike and the orebody came from a common magmatic source below. Pyrrhotite, which in many places is a high-temperature mineral, extends farther out from the dike than does the generally lower temperature chalcopyrite and gold, suggesting that as the dike and country rock cooled, the pyrrhotite formed early and the chalcopyrite and gold later as cooling progressed. This seems to be a strong case in support of Bruce's ideas. The dike consists of about 20 per cent plagioclase phenocrysts, $Ab_{60}An_{40}$, and a few hornblende phenocrysts, in a groundmass of fine grained albite, $Ab_{90}An_{10}$, with about 5 per cent hornblende and biotite, and a little quartz. In short, albite constitutes about 70 per cent of the dike rock, which is believed to have been given off by the same magmatic source that yielded the mineralizing fluids.

Cooke [15] finds that the original country rock of the Siscoe Mine consists of about 50 per cent chlorite and 35 to 40 per cent albite, $Ab_{90}An_{10}$. Near the vein, the partly altered rock contains 1 to 2 per cent chlorite, and about 80 per cent albite, and the remainder is mainly calcite with about 4 to 5 per cent quartz. The completely altered rock next to the vein is 95 per cent pure albite, $Ab_{100}An_0$. The alteration involved recrystallization of the albite into larger crystals of higher soda content, and addition of new albite. He concludes that, "the principal constituents of the vein-forming solutions must, therefore, have been soda, silica, and probably alumina, with lesser amounts of sulphur, boron, lime, and carbon dioxide."

Hawley [16] presents detailed petrographic descriptions and several chemical analyses showing the highly sodic nature of the sodic granodiorite series (granodiorite, fine diorite, albitite, granite and

[15] Cooke, H. C.: *op. cit.*, p. 94.

[16] Hawley, J. E.: Can. Min. & Met., Bull. (trans.) 1932, pp. 1–17.

granite porphyry, and lastly mica lamprophyre) with which the mineralization at the Siscoe mine is genetically related. The sequence was (1) quartz with little tourmaline or gold, cut by (2) andesite or fine diorite, cut by (3) albitite dikes, cut by (4) quartz-tourmaline-pyrite-gold veins. He suggests that the first formed fractures tapped off the early quartz, and that the next formed fractures extended farther down, deep enough to tap off the andesite and diorite. Since differentiation was progressing all the while, the later fractures tapped off successively later differentiates, and finally the ore-forming solutions of the last phase.

After mentioning the popularity of syenite porphyry with the prospectors as a guide to gold deposits, Cooke[17] says, "The work . . . suggests, however, that orebodies may be derived from other rocks besides the syenite porphyry. . . . In Dubuisson township . . . from granodiorite porphyry as well as from syenite porphyry. In Malartic township . . . (from) granite. On the Horne property . . . by segregation from a gabbro or norite magma." But these deposits conform to the generalizations proposed here, since both the Dubuisson rocks and the Malartic rocks are albitic, and the Horne mine ore consists predominantly of common sulphides with subordinate gold "precisely like the ores sunk from gabbro or norite intrusions as at Sudbury."[18]

Gussow[19] has made one of the best and most detailed studies of the relation of albite to gold among the Canadian deposits. He presents thirty excellent analyses and petrographic descriptions, showing that the Dufault, Flavian, and Bourlamaque masses are highly sodic and the others potassic. He plots on a map the points from which the analyzed specimens came, together with dots representing the gold deposits of the region, and concludes that ". . . the areal distribution of gold-sulphide deposits indicates a definite grouping about the sodic masses (Dufault, Flavian, and Bourlamaque). None seem related to the potassic masses."

Gunning and Ambrose[20] note that in the Cadillac-Malartic area

[17] Cooke, H. C.: *op. cit.*, p. 125.

[18] Cooke, H. C.: *op. cit.*, p. 119.

[19] Gussow, W. C.: Roy. Soc. Canada, Trans., 31: 129–161, 1937.

[20] Gunning, H. C., and Ambrose, J. W.: Can. Inst. Min. & Met., Trans., XL: 341–362, 1937.

of Quebec "The salient feature of the composition of all the acidic intrusives is their high content of soda feldspar (albite); orthoclase is very rare and microcline not abundant." They give numerous examples of claims and mines of the area, in which the quartz veins are associated with the albitic intrusives, and a genetic relationship is apparently implied although it is not specifically stated.

Similarly, Derry's [21] description of the Canadian Malartic Mine indicates that the gold metallization was closely related to, but followed, the albite mineralization of the pegmatites, and that this might be connected genetically to the same magmatic source that gave rise to the albitic porphyry. It is interesting that the ore in graywacke has a gold-silver ratio of 1.9: 1 whereas the pegmatite type of ore containing albite has a ratio of 6.28: 1.

Gunning [22] makes the significant observation that the gold-quartz veins of the Cadillac area caused no other change in the albitites in which they were deposited than a slight recrystallization of the albite, which he believes shows that the two were similar chemically. He presents evidence of the genetic relationship between the albitite and gold mineralization and concludes, "It seems to the writer that better evidence of close genetic relationship . . . could hardly be expected." L. V. Bell [23] reached a similar conclusion about the same deposits.

At the Amulet Mine,[24] in the Noranda District, and in the vicinity of the deposits of Ville-Marie and Guillet (Mud) Lake map-areas,[25] Quebec, albitic dikes and gold deposits occur, but no genetic relationship between them is postulated by the authors.

Langford,[26] referring to the McIntyre Mine, states that "the vein solution originated in the same magma that supplied the albitite dikes." The ores of the Howey Mine, Red Lake, Ontario, are related to a sodic oligoclase environment rather than to a truly

[21] Derry, D. R.: Econ. Geol., 34: 495–523, 1939.
[22] Gunning, H. C.: Canada Geol. Surv., Mem. 206: 20–23; 41–43, 1937.
[23] Bell, L. V.: Econ. Geol., 26: 630–643, 1931.
[24] Wilson, M. E.: Econ. Geol., 30: 478–492, 1935.
[25] Henderson, J. F.: Can. Geol. Surv., Mem. 201, 1936.
[26] Langford, G. B.: A. I. M. E., Tech. Pap. 903, 1938.

albitic environment, according to W. B. Mather.[27] Dougherty[28] pointed out the similarities of Porcupine and Kirkland Lake to one another and to the mines of Kolar, India. He says "The microgranite ('dogger') of Kolar, the successive intrusion of alaskite (quartz albite) porphyry and albitite at Porcupine, and the successive intrusion of basic syenite, acid syenite and syenite (albite) porphyry at Kirkland Lake, all prior to quartz lode deposition, suggest stages of magmatic differentiation from a common source." (The exact nature of the Kolar rocks is not given in the literature available; but apparently the age relations of the rocks and the origin of the ores are matters of controversy.)

On the other hand, Hurst[29] believes that the veins of Porcupine are structurally, but not genetically, related to the porphyries, and that the early deposition of albite in the veins "may be related to the hydrothermal alteration of wall rocks that are relatively rich in soda."

Seven successive periods of fracturing and re-opening of the Hollinger veins is found by Keys[30] with widespread deposition of albite in the second, and of gold in the fourth and fifth. A genetic connection between the albitite dikes that cut the porphyries but are earlier than the veins seems highly probable.

The gold-quartz veins of the Saint Anthony Mine,[31] Ontario, occur in albite granite country rock. Near the vein the granite, as shown by analyses, is impoverished in silica, sulphur, lime, and potash, and enriched in alumina, iron, and soda.

The igneous rocks associated with the gold deposits of Herb Lake were found by Stockwell to consist largely of soda feldspar. He says, "The veins may have been derived either from considerable depth in the porphyry bodies themselves, or, more probably, from an underlying magma that gave rise to both the porphyry bodies and the veins."[32] He finds a similar condition in the

[27] Mather, W. B.: Econ. Geol., 32: 131–153, 1937.
[28] Dougherty, E. Y.: Econ. Geol., 34: 622–653, 1939.
[29] Hurst, M. E.: Econ. Geol., 30: 103–127, 1935.
[30] Keys, M. R.: Econ. Geol., 35: 611–628, 1940.
[31] Moore, E. S.: Econ. Geol., 7: 751–761, 1912.
[32] Stockwell C. H.: Can. Geol. Surv., Mem. 208: 15–16, 1937.

Elbow-Morton area[33] of Manitoba, but in both cases stresses the occurrence of "quartz-eyes" in the sodic rocks, and cites the similar observations of L. V. Bell[34] in western Quebec, and Wright in many areas in Manitoba.[35, 36] Stockwell[37] likewise finds a close genetic connection between the veins of the Rice Lake-Gold Lake area and soda-rich feldspar rocks, for such feldspar is "a characteristic and abundant constituent of the dykes and also occurs in many of the veins and in the adjacent wall-rocks."

However, Reid[38] thinks that the intrusive porphyry at the San Antonio Gold Mine, at Rice Lake, was probably not the source of the ore. He finds "four eras of fracturing and five or possibly six of mineralization" of which two were auriferous. But albite was deposited in the earliest barren mineralization, and it is possible that both the porphyry and the ore-forming solutions came from a common magma source below.

A considerable pause, during which differentiation toward the albitic end apparently occurred, is indicated by Horwood's[39] description of the Argosy Gold Mine, Casummit Lake, Ontario. "The veins were formed after the late Algoman (?) diorite dykes (75 per cent andesine) and before the post-Algoman (?) lamprophyre dykes." The close association of the diorite dikes and the veins is believed to indicate a genetic relationship. "It is probable that the dykes are the only surface expression of an intruding magma, and that they were injected at an early stage of the intrusion. Later, when much of the magma had crystallized and water and the other mineralizers had accumulated, the resulting hydrothermal solutions escaped, followed the easiest pathways upwards—the fractures not filled by the dykes—and formed the auriferous quartz veins." The veins contain "occasional crystals of albite," and small amounts of common sulphides. Both the first and second generations of mineralizing solutions deposited

[33] Stockwell, C. H.: Can. Geol. Surv., Mem. 186: 13, 1935.
[34] Bell, L. V.: Bull. Can. Inst. Min. & Met., May 1936, pp. 249–251.
[35] Wright, J. F.: Trans. Can. Inst. Min. & Met., 38: 259, 1935.
[36] Wright, J. F.: Can. Geol. Surv., Mem. 169: 56, 1932.
[37] Stockwell, C. H.: Can. Geol. Surv., Mem. 210: 36, 1938.
[38] Reid, J. A.: ECON. GEOL., 26: 644–661, 1931.
[39] Horwood, H. C.: Can. Inst. Min. & Met., Trans., XL: 210–228, 1937.

quartz, carbonates, and albite; and these were followed by fracturing before the introduction of the sulphides and gold.

Thus, all the Canadian Shield deposits, of which descriptions were encountered that contained precise information on the feldspars, conform to the generalizations presented above.

Finally, with regard to the Canadian Shield, Osborne [40] points out that the rocks of the Quebec-Ontario gold belt are typical of the trondhjemite [41] stem, which, as will be seen below, is apparently a point of major importance.

NEWFOUNDLAND.

In the Sops Arm area, White Bay, Newfoundland, Heyl [42] finds that the Paleozoic granites contain dominant microcline with a little albite, $Ab_{92}An_8$, and the associated aplites consist of quartz, microcline, and albite. Some of the minor intrusive rocks contain intermediate plagioclase; but the most abundant igneous rocks of the area are the " felsic dyke rocks," some of which are quartz keratophyres, in which the dominant constituent is albite, $Ab_{95}An_5$. These are closely associated areally with the auriferous quartz veins, and a genetic relationship seems likely. Heyl [43] shows also that in the Bay of Exploits area there are gold quartz veins and the main intrusive sequence is granitic, characterized by high soda content, but he presents no conclusion of origin of the ore.

BRITISH COLUMBIA AND ALASKA.

The Pacific coast region of Alaska and Canada provides many examples of a genetic relationship between gold and albite. Osborne [44] points out that the Coast Range batholith belongs to the granodiorite stem, intermediate between the trondhjemite and gabbro stems. He says, " In the Coast Range stem an enrichment

[40] Osborne, F. F.: Roy. Soc. Can., Trans., 31: 127, 1937.

[41] Trondhjemite is an abyssal igneous rock containing predominant plagioclase (oligoclase or andesine) with about 20 per cent of quartz, less than 10 per cent of mafics, and only very subordinate quantities of potash feldspar.

[42] Heyl, G. R.: Newfoundland Dept. Nat. Res., Geol. Sect., Bull. 8: 1–42, 1937.

[43] Heyl, G. R.: Newfoundland Dept. Nat. Res., Geol. Sect., Bull. 3, 1936.

[44] Osborne, F. F.: *op. cit.*, p. 128.

in soda is found, giving local pockets of rocks of the trondhjemitic type. It is interesting in this connection to notice the frequent mention of albite-rich rocks in association with gold deposits. Albite-rich rocks are commonly developed in the trondhjemite stem."

The ore of the Treadwell Mine consists of mineralized albite-rich dikes, first called by Becker[45] "sodium syenite," and later named "albite-diorite" by Spencer.[46] They are, however, quite similar in composition to some of the abundant dikes of the Yukon gold district described by Spurr,[47] which he called alaskite.[48] But Spencer emphasized the secondary nature of the albite, and believes that contemporaneously with the mineralization, the earlier formed microperthite was broken down, yielding albite by a process of albitization[49] in situ, as it were. Similar albitic dikes associated with gold mineralization have been described from Funter Bay on Admiralty Island,[50] and from Chichagof Island.[51] Reed[52] has shown that the Hirst Chichagof vein is more productive where the albite-aplite forms the footwall, but he makes no postulate of ore genesis. Knopf[53] described a gold-bearing albitic dike in the Eagle River Region, and suggested that the albite was introduced.

Referring to the Skeena River District of British Columbia, Kerr[54] says, "In general, the intrusives that are variable in character due to differentiation, especially those high in acid plagioclase, are by far the most important producers of mineral deposits. Deposits (intrusives) high in albitic plagioclase commonly have associated mineral deposits, and these generally have a high gold content. The uniform intrusives, especially some fairly high in orthoclase and intermediate plagioclase, have not produced much important mineralization. . . . Earlier Triassic

45 Becker, G. F.: U. S. Geol. Surv., 18th Ann. Rept., Pt. III: 7–86, 1898.
46 Spencer, A. C.: A. I. M. E. Trans., 35: 473–510, 1904.
47 Spurr, J. E.: U. S. Geol. Surv., 18th Ann. Rept., Pt. III: 297–313, 1898.
48 Spurr, J. E.: Amer. Geol., 25: 230, 1900.
49 Spencer, A. C.: *op. cit.*, p. 505.
50 Mertie, J. B.: U. S. Geol. Surv. Bull. 714–B: 114–115, 1919.
51 Buddington, A. F.: U. S. Geol. Surv. Bull. 773: 114–124, 1923.
52 Reed, J. C.: A. I. M. E. Tech. Pap. 1051, 1939.
53 Knopf, A.: U. S. Geol. Surv. Bull. 502: 36, 1912.
54 Kerr, F. A.: Econ. Geol., 33: 428–439, 1938.

and Jurassic acid plagioclase diorites and quartz diorites were responsible for most of the mineral deposits, especially those high in gold. Some intrusives high in orthoclase in the Stikine River area also produced mineral deposits, but these are mainly low in gold."

At Barkerville, Cariboo District, B. C., many of the acidic sills that contain "albite-oligoclase," "are seamed with a network of veins, some of which carry iron and lead sulphides and gold values,[55] but the authors do not discuss the origin. Albite has been observed in some of the gold-quartz veins of the Lardeau Map-area, B. C., thought to have been derived from the same magmatic source as were the rocks of the Kuskanax batholith.[56]

The gold deposits of the Bridge River district of British Columbia show a particularly interesting relationship to the more sodic rocks, as first recognized by Bateman.[57] Cairnes[58] recently divided the gold deposits into two groups. In the older group (probably Jurassic) "The deposits are associated, principally, with those Bralorne intrusive bodies in which variations in composition from augite diorite to highly siliceous, soda granite are characteristic features. The variation is attributed to differentiation prior to intrusion and the mineral deposits themselves are regarded as a late, probably the last, phase of this differentiation." In the less sodic and siliceous parts, no gold deposits are found, and the close relationship to the soda granite, composed of about equal amounts of albite and quartz together with about ten per cent of dark minerals, and to the albitite and other albitic dikes, is strikingly evident. "Recent work, at depth, on the Pacific Eastern gold property, . . . has discovered some soda granite differentiates and, in their vicinity, some high-grade gold quartz ore." The second type of deposit in the Bridge River district is associated with the Bendor intrusives (probably post Lower Cretaceous). These are for the most part copper deposits, or others in which the gold is distinctly subordinate. But those deposits

[55] Johnston, W. A. and Uglow, W. L.: Can. Geol. Surv., Mem. 149: 17, 1926.
[56] Gunning, H. C.: Can. Geol. Surv., Mem. 161: 31, 1929.
[57] Bateman, A. M.: Can. Geol. Surv., Summ. Rept., 1912, pp. 188–210.
[58] Cairnes, C. E.: Can. Geol. Surv., Mem. 213, 1937.

genetically related to the Bendor that are high in gold, are associated with the more sodic, satallitic acid dike rocks, some of which are definitely albitic.

CALIFORNIA.

"Forming numerous dikes along the belt of quartz mines of the Mother Lode are white rocks which at some points contain quartz and muscovite, but which at many points are made up chiefly of . . . albite."[59] Some are directly associated with gold deposits in Eldorado County,[60] as at the Shaw, Big Canyon, and Bachelor mines.[61] Auriferous albitic dikes have also been worked on Moccasin Creek and Kanaka Creek (Willietta Mine) in the Sonora section.[61] Turner[62] says, "The association of gold with soda feldspar dikes, so far as my observation goes, is more frequent than with dikes of other rocks. . . ." It is noteworthy that the gold here, as elsewhere in auriferous albitic dikes, is generally in the net-work of quartz and albite filled fractures in the dikes. Blake[63] had observed gold in an aggregate of albite and quartz from the Armagosa gold mines in San Bernardino county as early as 1864.

Lindgren[64] rejected lateral secretion as the origin of the California gold-quartz veins, and in the first and subsequent editions of his "Mineral Deposits" conceded "that in many places the evidence points to the gabbro and peridotites (from which the serpentine was derived) and to the numerous albite aplite dikes which accompany the basic intrusions as a source of at least part of the gold." In reference to this statement, Ferguson[65] points out that "no important basic intrusives occur in the Silver Peak district which has been the most important of the pre-Tertiary gold camps

[59] Turner, H. W.: U. S. Geol. Surv., 17th Ann. Rept., Pt. I: 663, 1896.
[60] Turner, H. W.: Am. Jour. Sci. (3), 47: 470, 1894.
[61] Turner, H. W.: Jour. Geol., 7: 389–400, 1899.
[62] Idem, p. 398.
[63] Blake, W. P.: A. I. M. E. Trans., 26: 292, 1896.
[64] Lindgren, W.: Mineral Deposits, 1st edit., p. 540, 1913.
[65] Ferguson, H. G.: Econ. Geol., 24: 128, 1929.

of western Nevada." Silver Peak is, furthermore, one of Spurr's [66] best examples of association of ore with alaskite.

The rocks of Silver Peak contain both potash feldspars and albite, but K_2O exceeds Na_2O in all the analyses given. The petrographic descriptions are not precise, and since some of the veins were worked primarily for gold and others primarily for silver, detailed study might disclose a difference in the feldspars of the intrusives connected with the different types of ore. The ratio of gold to silver is not given, but the silver veins apparently contain additional metallic elements and larger quantities of sulphides. A detailed investigation into the differentiation history to see what correlation, if any, could be made between the petrography of the individual intrusives and the Au:Ag ratio of the associated veins, might provide a good test of the thesis of this paper.

Knopf [67] stresses that in the Mother Lode deposits "the effect of carbon dioxide and the potassium vastly exceeded that of the other constituents" of the vein forming solutions. And further, he states, "Which magma or magmas supplied the gold and other constituents is unknown. The attempt to ascribe their origin to gabbro, peridotite, and albite aplite dikes finds no support from the mode of occurrence of the gold along the Mother Lode belt; in fact, the belt is particularly poor in gold where these intrusions are most abundant. It appears to be a safe conclusion, however, that the ore-forming emanations were given off during the final stages of the epoch of plutonic intrusion at or near the end of Jurassic time," that is, at the end of the period of regional intrusion of granodiorite batholiths.

Ferguson and Gannett find that the deposits of the Alleghany [68] District of California are genetically associated with granites and aplite in which the feldspar is in most cases albite, though rarely it may be oligoclase. They find that early in their second stage of the mineralization process (Knopf [69] thinks this is the first stage, for he rejects their first or chloritic stage as being so early as to

[66] Spurr, J. E.: U. S. Geol. Surv. Prof. Pap. 55, 1906.
[67] Knopf, A.: U. S. Geol. Surv. Prof. Pap. 157: 47–48, 1929.
[68] Ferguson, H. G., and Gannett, R. W.: U. S. Geol. Surv. Prof. Pap. 172, 1932.
[69] Knopt, A.: Econ. Geol., 28: 399–401, 1933.

be unrelated) the favorable wall rocks were replaced by calcic albite and oligoclase and there was "minor crystallization of albite within the veins." They believe that the lime of the newly formed albite and oligoclase in the wall-rock was derived from the wall-rock, and hence the mineralizing solutions were higher in soda and lower in lime than the resulting plagioclase might suggest. Ferguson[70] has also shown a close genetic relationship between gold deposits of the Klamath Mountains and soda granite porphyry.

Describing the Shady Run mine in the eastern part of the Mother Lode, Reid[71] says, "The source of the ore is connected with the dike itself, as the gangue minerals are the same. The solutions were evidently rich in alkaline carbonates, and probably represented the last stages of consolidation of the acid magma below." Albite is the chief constituent of the dike.

The veins of the Alamo gold district[72] of Lower California are associated with non-potassic rocks. The country rock is quartz diorite ($Ab_{55}An_{45}$ to $Ab_{25}An_{75}$) cut by hornblende porphyry dikes ($Ab_{55}An_{45}$) that structurally controlled the ore deposition. Albitization attended the vein formation, and although Moehlman does not relate the mineralization to any specific rock, a large mass of sodaclase granite lies to the west of the deposits, composed of about equal parts of perthite, albite-oligoclase, and quartz, with a little biotite.

AMERICAN CORDILLERAN.

The Cordilleran mining regions offer little positive evidence of genetic relationship between albite and gold. The negative evidence, for what it may be worth, is abundant in the hundreds of non-auriferous mines with which no albite-bearing rocks have been noted. Much of the gold that has been won in this region has come from mixed ores and the evidence suggests that the polymetallic deposits and albitic intrusives are antithetic.

[70] Ferguson, H. G.: Econ. Geol., 10: 241–261, 1915.
[71] Reid, J. A.: Min. & Sci. Press, March 2, 1907, pp. 279–280.
[72] Moehlman, R. S.: Econ. Geol., 30: 750–764, 1935.

The differentiation history [73] of the Front Range intrusives of Colorado shows a progression toward sodic types, but these were followed by granitic and then by "alkalic" rocks, before the introduction of the ores, and these are notably polymetallic in character.

In a more detailed treatment [74] of the same subject the sequence is given as "diorite, monzonite, quartz monzonite, granite, alaskite, lead-silver-zinc ores; alkalic syenite, bostonite, pyritic gold ores; biotite monzonite, biotite latite, latite intrusion breccia, gold-telluride ores." Chemical analyses are given, and it is noteworthy that the bostonite preceding the pyritic gold ores has 7.19 per cent K_2O, and 3.95 per cent Na_2O. In fact the whole series is notably potassic. It clearly belongs to the potash-granite stem, and is unrelated to the trondhjemitic stem.

In the Philipsburg quadrangle of Montana, the igneous rocks range from basic to acidic types and many of the latter are notably albitic. Abundant albite and scapolite in the metamorphic rocks suggest a considerable transfer of soda by the metamorphosing solutions. Some of the veins carry gold with little silver, and others carry silver with little gold, but Emmons and Calkins [75] make no correlation between the soda content of the attendant igneous rocks and the Au : Ag ratio of the veins.

Likewise, other gold deposits of the vast Rocky Mountain-Cordilleran region show no relation to albitic intrusives. Some, on the other hand, show a clear association with distinctly potassic rocks. But the gold deposits of this region are dissimilar to those of Canada and the Pacific coast in many other respects than just the matter of genetic association with sodic igneous rocks, and an outstanding feature is the polymetallic nature of the ores, and the subordinate, commonly bi-product, nature of the gold.

HOMESTAKE MINE.

The origin of the Homestake deposits has been the subject of considerable controversy, but whether the mineralization is ge-

[73] Lovering, T. S.: U. S. Geol. Surv. Prof. Pap. 178, 1935.
[74] Lovering, T. S., and Goddard, E. N.: G. S. A. Bull. 49: 67, 1938.
[75] Emmons, W. H., and Calkins, F. C.: U. S. Geol. Surv. Prof. Pap. 78, 1913.

netically related to the Harney Peak (Algoman) granite or to the Tertiary rhyolitic intrusives, or both, makes little difference here because both are somewhat albitic. Wright [76] favors both periods, with the second most important, and gives three analyses of the rhyolite that show extreme potash content at depth, diminishing toward the surface, with intermediate plagioclase in the medium depths, and sodic plagioclase nearer the surface. Quoting only the pertinent parts:

	1500 ft. level.	2500 ft. level.	Deep drilling.
Silica	70.3	69.15	70.3
Alumina	14.3	14.4	14.4
Lime	0.9	2.24	0.6
Soda	3.6	2.4	0.4
Potash	6.1	6.24	12.4

Only three analyses is a slender thread to follow, but these suggest a possible significant relationship. Semenenko [77] records a similar transition at the iron deposits (non-auriferous) of Krivoi Rog, Russia, where the genetically related albite pegmatites become richer in orthoclase at depth.

SOUTHERN APPALACHIANS.

The feldspars are not described in sufficient detail in the accounts of these deposits. Graton [78] thought that both the tin-tourmaline veins and the somewhat similar gold-quartz veins were probably genetically related to the granitic or aplitic dikes. Assays of the veins associated with such dikes at the Jones mine and Faires mine show small amounts of gold. The only feldspar mentioned as occurring in the pegmatite of the Faires mine is albite, and the rocks of this mine are said to be similar to those of the Jones mine. But most of the several varieties of pegmatites commonly contain dominant potash feldspar, although they have apparently suffered various moderate degrees of albitization.

[76] Wright, L. B.: A. I. M. E., Tech. Pap. 699: 19, 1936.

[77] Semenenko, N. P.: Acad. Sci. Ukrainian S. S. R., Inst. Geol. (Kiev), Jour. Geol., V (3): 71–72, 1938.

[78] Graton, L. C.: U. S. Geol. Surv. Bull. 293: 9–118, 1906.

MEXICO, CENTRAL AND SOUTH AMERICA.

There is a paucity of data on the composition of the feldspars genetically related to the gold deposits of Mexico, Central America, and South America, but for the most part the deposits seem to carry silver in excess of gold, and are apparently not accompanied by albitic rocks.

Krieger [79] describes an altered dike that originally contained orthoclase and albite that is followed by a quartz-carbonate-feldspar vein carrying gold and uraninite. De Oliveira [80] mentions that albite occurs in the ores of Morro Velho, and in the similar Cuyaba mine there is a "considerable rocky body" of coarse granitic texture, "composed essentially of plagioclase. . . ." The relationship of Morro Velho to oligoclase pegmatites, and the albite of the veins has been mentioned by others [81] but the data is inadequate.

The best veins of the Zaruna Gold District of Ecuador [82] occur where the main granodiorite intrusive contains "segregations of alaskite," but the exact nature of the plagioclase is not clear.

SOUTH AFRICA.

Excluding the auriferous conglomerates of the Rand type, of debatable origin, the gold deposits of South Africa fall into two genetic groups, (1) those related to the Older Granite, and (2) those related to the younger Bushveld Granite.

The deposits of the Murchison Range and of the Barberton Range fall in the first category. Mendelssohn [83] states that in the Murchison Range "oligoclase is present in minor amounts" in the banded iron-stone wall rocks, "and since it also occurs in the bands of white vein quartz, it has probably been introduced by the hydrothermal solutions." The gold deposits of the Barberton

[79] Krieger, P.: Econ. Geol., *27*: 651–660, 1932.

[80] De Oliveira, E. P.: In The Gold Resources of the World. XVth Int. Geol. Cong., Pretoria, 1930, pp. 58–59.

[81] For refs. see Emmons, W. H.: Gold Deposits of the World, McGraw-Hill Book Co., N. Y., 1937, pp. 297–300.

[82] Billingsley, P.: A. I. M. E., Trans., *74*: 255–275, 1926.

[83] Mendelssohn, E.: Geol. Soc. South Africa, Trans., *41*: 249–272, 1938.

district appear to be related to the Older Granite, which is shown by Hall [84] to be potassic. But some of the deposits are connected with pegmatites that are albitic, and others are associated with acidic dike rocks for which the feldspar compositions are not given. That a differentiation sequence toward albite-rich fractions has taken place is shown by LeGrange [85] and by Van Eeden et al.[86] LeGrange [85] has demonstrated that the Palabora and Barbara pegmatites, which are genetically related to the pegmatites of the Older Granite, are strongly albitic. Apparently it was characteristic of the Older Granite to yield pegmatites rich in albite as a late differentiation product as shown by Gevers and Frommurze [87] at the Erongo tin deposits and Gevers [88] in his excellent study of the Namaqualand pegmatites.

Of the younger group, the Pilgrims Rest deposits are attributed by Reinecke and Stein [89] to the regional granite, which consists of quartz, orthoclase slightly in excess of oligoclase ($Ab_{75}An_{25}$), and a little magnetite but no ferromagnesian minerals. The rock is therefore alaskitic and appears to have trondhjemitic characteristics. Lombaard [90] has shown that the felsites, which were a very late phase of the Bushveld differentiation, even younger than the granite, are generally characterized by an abundance of albite phenocrysts.

About 140 miles northwest of the Rand lies the Batavia goldfield,[91] where gold occurs in a conglomerate of the Black Reef series, which is younger than the Witwatersrand System and separated stratigraphically from it by the Ventersdorp System. The younger red granite outcropping to the southwest contains

84 Hall, A. L.: South Africa Geol. Surv., Mem. 9, 1918.

85 LeGrange, J. M.: Geol. Soc. South Africa, Trans., 32: 1–25, 1929.

86 Van Eeden, O. R., Partridge, F. C., Kent, L. E., and Brandt, J. W.: South Africa Geol. Surv., Mem. 36, 1939.

87 Gevers T. W., and Frommurze, H. F.: Geol. Soc. South Africa, Trans., 32: 111–150, 1929.

88 Gevers, T. W.: Geol. Soc. South Africa, Trans., 39: 331–378, 1936.

89 Reinecke, L., and Stein, W. G. A.: Geol. Soc. South Africa, Trans., 32: 65–88, 1929.

90 Lombaard, B. V.: Geol. Soc. South Africa, Trans., 35: 125–190, 1932.

91 Wagner, P. A., and Ross, W. O. C.: South African Jour. of Indus., Sept., 1925, pp. 1–24.

notable amounts both of orthoclase and oligoclase, and is thought to belong to the Bushveld granite. It is intrusive into the Ventersdorp. Diamond drill holes show that the granite extends northeastward below the surface, toward the reef, and the reefs have a general southwesterly dip toward the granite. About three to four miles east of the deposits, the Ventersdorp is cut by pink syenite dikes of unspecified feldspar content. It is not impossible that at least this conglomerate was mineralized by the younger Bushveld Granite.

Thus, both the Older Granite, and the younger Bushveld granite, yielded gold deposits and albite-rich differentiates. It is possible that the gold and albite may bear some genetic relationship to one another.

SOUTHERN RHODESIA.

The relationship of the gold deposits of Southern Rhodesia to the margins of the granite batholiths was early emphasized by Mennell.[92] Also with a general marginal relationship to the granites with which they are probably genetically related, are abundant, fine-grained, acid, dike rocks. Maufe[93] pointed out that the association of these acid dikes with the gold deposits was too common to be coincidental, and postulated a genetic relationship between them. He listed thirty mines or districts in Southern Rhodesia where the association was evident, but did not mention the composition of the contained feldspars. However, the albitic character of many of these dikes is brought out in the later, more detailed reports of the Southern Rhodesia Geological Survey, and furthermore, the descriptions of some of the pre-Cambrian rocks indicates that they may belong to the trondhjemite stem.

All the chief types of granitic rocks in the Mazoe Valley Gold Belt[94] are essentially soda-granites, and the minor stocks, with which many of the gold deposits are associated, consist of about fifty per cent idiomorphic "soda-rich plagioclase," and are so low in quartz as to be really tonalites. The origin of the gold de-

[92] Mennell, F. P.: The Rhodesian Miner's Handbook. Bulawayo, 1908, p. 35.
[93] Maufe, H. B.: South. Rhod. Geol. Surv., Bull. 2, 1913.
[94] Tyndale-Biscoe, R.: South. Rhod. Geol. Surv., Bull. *22*, 1933.

posits appears to have been: first, quartz-porphyry sill and dike intrusions; second, the principal period of granitic intrusion as batholiths and stocks; third, consolidation, cooling and contraction, resulting in zones of fissuring and shearing, up some of which the more volatile fractions of the magma forced their way, forming pegmatites, aplites, and auriferous veins; fourth, intrusions of acid granitic magma in the western part of the area, followed by pegmatites, but not, apparently, by auriferous veins.

The dikes and sills associated with the mineralization of the Connemara [95] mine in the Gwelo District "consist of about fifteen per cent quartz and the rest is mainly albite, heavily sericitized." Furthermore, the map shows a close spatial relationship between the gold deposits and the soda-granite and soda-tonalite masses in which soda exceeds potash, and albite is abundant.

In the Umtali [96] district, by far the greater part of the gold output has come from the Penhalonga Valley which is the only portion of the mapped area that contains porphyries and felsites. The descriptions of the feldspars of these rocks are not very specific, but apparently they are "oligoclase to andesine," although the dikes at the Battersea mine and at the Iona West mine contain abundant albite and are "approaching quartz-soda-syenite in composition and closely resemble albitite." Phaup remarks upon the common, frequent, abundant, and close association of the dikes and ore, and says, "some appear to be very closely related genetically to the gold mineralization."

In the Lower Umfuli Gold Belt,[97] of the Hartley and Lomagundi districts, the Giant mine has yielded about eighty-four per cent of the gold production. "The company reports make frequent mention of an acid dyke found in association with the ore body." Similar minor acid intrusives occur near other mines of the region. But the petrographic descriptions are vague about the composition of the plagioclase, and although it generally seems to be no more sodic than oligoclase, the one chemical analysis given shows normative albite.

[95] Macgregor, A. M.: South. Rhod. Geol. Surv., Bull. 31, 1937.
[96] Phaup, A. E.: South. Rhod. Geol. Surv., Bull. 32, 1937.
[97] Phaup, A. E., and Dobell, F. O. S.: South. Rhod. Geol. Surv., Bull. 34, 1938.

Three granites occur in the Antelope Gold Belt, (1) the old gneissic granite, (2) the porphyritic granite, and (3) the younger granite. Phaup [98] finds that the pegmatites, aplites, and alaskites, many of which are highly albitic, that were late but genetically related phases of the younger granite, cut the ore, and are therefore younger than the mineralization. But this seeming anomaly is explained by his conclusions in the Lower Gwanda Belt.[99] The deposits of this belt resemble those of the Antelope belt, and all are markedly unlike the other gold deposits of the country, chemically, mineralogically, and otherwise. He concludes, "Thus these ores appear to be a higher temperature type, of older age, connected with the old porphyritic granite and unrelated to the major gold mineralization of Southern Rhodesia."

OTHER AFRICAN EXAMPLES.

Gallagher [100] concluded that the gold-quartz veins of the western Lupa Goldfield in Tanganyika were genetically related to a widespread regional intrusion of alaskite that consisted mainly of about equal proportions of quartz, orthoclase, and albite. At Kirondatal in the Iramba Plateau, R. B. McConnell of the Tanganyika Geological Survey has observed an "aplogranite" [101] quartz vein intersection in greenstone. Within the greenstone the vein carries no values, but at the intersection the vein is auriferous and the aplogranite "has become albitized, presumably on account of the sodic solutions in the vein-channel." G. M. Stockley observed that the Kiabakari mine in the Musoma district is an auriferous aplite consisting largely of albite and quartz with sulphides.[102]

A multiplicity of acidic, feldspathic dike rocks occurs at the gold deposits of the Mwanza district of Tanganyika, but although the origin of the ore is thought to be connected with at least some of them, the feldspars have not been described in detail.[103] Their

[98] Phaup, A. E.: South. Rhod. Geol. Surv., Bull. 21, 1932.
[99] Phaup, A. E.: South. Rhod. Geol. Surv., Bull. 24, 1933.
[100] Gallagher, D.: ECON. GEOL., 34: 243–267, 1939.
[101] Aplogranite (Bailey 1916) synonymous with alaskite (Spurr 1900).
[102] Personal communication from Mr. Frank Oates of the Tanganyika Geol. Surv.
[103] Wade, F. B., and Oates, F.: Tanganyika Geol. Surv. Short Pap. 12, 1934.

similarity to the deposits of Southern Rhodesia has also been pointed out by Tyler.[104]

The gold-quartz veins of Urega, Kivu, Belgian Congo, were derived from the albite pegmatites with which they are associated, according to Van Aubel.[105] And the gold reefs of Ashanti in the Gold Coast are believed by Junner [106] to be genetically connected with the albite-granite that outcrops to the west of Obuasi.

AUSTRALIA.

McLaughlin [107] has drawn an illuminating comparison between the gold deposits of Australia and North America, which is, in tabular summary:

Western Australia (Kalgoorlie) = Ontario.
Victoria and N. S. W. = California, B. C., and Nova Scotia.
Bendigo = Nova Scotia structurally and otherwise.
Bendigo = Mother Lode and Bridge River mineralogically.
Kalgoorlie = Porcupine in structure and rocks.
Kalgoorlie = Kirtland Lake in ores and mineralogy.

Genetic association with albitic intrusives might, therefore, be expected of the Australian deposits, but as will be seen below, the available data are inadequate.

Gustafson and Miller [108] note small, late, albite porphyry dikes at Kalgoorlie, and "the gold-bearing solutions probably came from the underlying granite batholith, as did the porphyry dikes at a slightly earlier date." In regard to this, Stillwell [109] says, "The differentiation processes in the magma reservoir which led to the formation of the dike magma, I regard as a prelude to the formation and introduction of the auriferous solutions. The common association of porphyry dikes and ore bodies, not only in

[104] Tyler, W. H.: Min. Mag. (London), 56 (3): 137–145, 1937.
[105] Van Aubel, R.: Ann. de la Soc. Geol. de Belgique, publ. spec. au Congo Belge 1933–34, p. 9.
[106] Junner, N. R.: Gold Coast Geol. Surv., Mem. 2, 1932.
[107] McLaughlin, D. H.: Roy. Can. Inst. Proc., Ser. IIIA (2): 53–62, 1937.
[108] Gustafson, J. K., and Miller, F. S.: ECON. GEOL., 32: 285–317, 1937.
[109] Stillwell, F. L.: ECON. GEOL., 33: 108–112, 1938.

Kalgoorlie but throughout Western Australia, suggests that the association is not purely structural but has a genetic significance."

Blatchford [110] makes a three-fold division of the Western Australia deposits with respect to their attendant acidic dikes; (1) lode deposits preceded by dikes, (2) quartz veins cut by dikes, and (3) auriferous dikes. He says, of the Golden Mile, Kalgoorlie, "Following the intrusion of the quartz dolerite, intense shearing and faulting took place. . . . Probably during this period or at most a short period afterwards, the albite porphyries forced their way in and were undoubtedly followed by a second period of shearing. It was not until after the second period shearing took place that the mineralization of formation of the lodes commenced." However, although albite is not mentioned as a constituent of the ore of the Wiluna Gold Mines in the East Murchison Goldfield, the chemical analysis suggests its possible presence. Further, he states of the Meekatharra deposits, "The gold solutions apparently came from the same magma as the porphyry and were circulating through the ore channel before the acid rock had completely solidified." Of the quartz veins he says, "One important geological feature which is common to most reefs is that they are very frequently cut by acid dykes. These dykes have proved to be post gold deposition and have had no bearing whatever on the gold contents." Lastly, he mentions gold-bearing alaskites and auriferous aplites, but their petrography and origin are not given.

It was the gold deposits of Victoria that prompted Thomas Belt to anticipate in 1861 some present day ideas. He claimed "that the auriferous quartz reefs of Victoria were formed as igneous intrusions and that they represented the extreme acid final stage of some quartz felspar dikes of which all the felspathic material had been removed by its crystallization and retention in some lower zone." [111] Junner [111] reviews the deposits of Victoria and relates them genetically with rocks of intermediate acidity. He says, "The richest auriferous reefs are connected with rocks of dioritic

[110] Blatchford, T.: In The Gold Resources of the World. XVth Int. Geol. Cong., Pretoria, 1930, pp. 427–457.

[111] Junner, N. R.: Econ. Geol., 16: 79–113, 1921.

or gabbroidal composition . . . the reefs connected with more acid and more basic types have yielded little gold." He lists Maryborough, Maldon, Stawell, Ballarat, Blakeville near Ballan, Foster, and Yarra, as being connected with felsitic and quartz porphyry dikes, but the details of the feldspars are not given.

Stone [112] states that " the only intrusive rocks seen in the (Bendigo) mines are the lamprophyre or ' lava ' dykes, which are . . . later (Tertiary [113]) than the quartz reefs and cut them in many places." He [114] prefers the suggestion of a deeply buried source rock—an underlying batholith. But Blanchard [115] argues that the deposits are not lower than leptothermal, and so they may not belong to the type under consideration here. However, Lindgren [116] reports the occurrence of albite in vugs in the vein quartz at Bendigo.

The famous deposits of Queensland, such as Charters Towers, Mount Morgan, Gympie, and Mount Isa, are not intimately associated with igneous rocks that are clearly related genetically to the mineralization, and such rocks as do occur are mainly diorites to hornblende granites. Morton,[117] however, relates the Charters Towers mineralization to diorite-porphyrite dikes of unspecified composition.

It may be significant that the Protogine granite of South Australia, containing albite nearly equal in amount to potash feldspar, gave rise to the potash-rich pegmatites that grade into the veins, and acted as ore bringers, in the Broken Hill area, for the resulting deposits are silver-lead-zinc ores with only a trace of gold.[118]

NEW ZEALAND.

The gold deposits of New Zealand fall naturally into three contrasting groups: (1) the Otago district in the south, of unknown

112 Stone, J. B.: Australian Inst. Min. & Met., Proc. (New Ser.), No. 102: 1–23, 1936.

113 Edwards, A. B.: Econ. Geol., 33: 349–351, 1938.

114 Stone, J. B.: Econ. Geol., 32: 894, 1937.

115 Blanchard, R.: Econ. Geol., 33: 218–225, 1938.

116 Lindgren, W.: Econ. Geol., 1: 163–166, 1905–06.

117 Morton, C. C.: In The Gold Resources of the World. XVth Int. Geol. Cong., Pretoria, 1930, p. 283.

118 Mawson, D.: Roy. Soc. of South Aust., Mem., II, Pt. 4, 1912.

origin, (2) the West Coast area, of probably sodic association, and (3) the Hauraki region on the northeast coast of the North Island, of potassic association.

There are no known intrusive or volcanic rocks in the Otago district, but Williamson[119] suggests that the extensive metamorphism of the rocks, and the presence of scheelite in some of the veins indicates an underlying magma.

In the West Coast area Collingwood is the only productive district of the veins connected with the older Paleozoic granite, in which ". . . feldspars are the most abundant minerals, orthoclase and albite being present in all specimens. . . ."[120] The Reefton, Westport Lyell, Paparoa, and Ross deposits are related to the younger granites of late Jurassic age.[121] The petrographic descriptions[122] of these rocks indicate that the feldspars present are potash feldspars or intermediate plagioclase. However, the chemical analyses and norms show an entirely different character; the granite contains $Ab_{89}An_{11}$ nearly equal to potash feldspar in amount, and is low in mafics; the aplite contains $Ab_{98}An_2$ greatly in excess of potash feldspar; and of the two pegmatites given, one is a highly sodic tourmaline pegmatite. Other evidence[123] of the presence of albite-rich igneous rocks in New Zealand is coming to light, and although detailed evidence is lacking, the mineralization of the gold deposits has been attributed to the granitic rocks, and there is evidence that they are, at least in part, albitic.

The deposits of the Hauraki Goldfield, as well as those of Tavua, Fiji Islands, have been compared by McLaughlin[124] to the gold-silver deposits of Mexico, Nevada, and the North American Cordillera, generally associated with volcanic rocks. The rocks of Hauraki are potassic effusives, and the district is one of the great silver-gold producers of the World, with the silver-gold ratio 6 to 1.[125]

119 Williamson, J. H.: N. Zealand Geol. Surv., Bull. 39: 74, 1939.

120 Ongley, M., and MacPherson, E. O.: N. Zealand Geol. Surv., Bull. 25: 24, 1923.

121 Henderson, J.: In The Gold Resources of the World. XVth Int. Geol. Cong., Pretoria, 1930, p. 260.

122 Morgan, P. G., and Bartrum, J. A.: N. Zealand Geol. Surv., Bull. 17, 1915.

123 Bartrum, J. A.: Roy. Soc. New Zealand, Trans. & Proc., 65 (2): 95–107, 1935.

124 McLaughlin, D. H.: *op. cit.*

125 Von Bernewitz, M. W.: Chem. Eng. & Min. Rev., 26: 197–201, 233–236, 1934.

ASIA.

The gold-quartz veins of José Pañganiban,[126] Camarines Norte, Philippine Islands are genetically related to an albite granite nearly identical[127] to the Saza, Tanganyika, alaskite. There are also many consanguineous albitic dike rocks present.

Willbourn[128] concluded that the mineralization of the Raub deposits of Pahang, Federated Malay States, was genetically related to the Bukit Kajang granite-porphyry, a late phase of the granite, rather than to the pre-granite Pahang volcanics. He also describes the abundant related acid dikes that are "riddled with a network of auriferous quartz-veinlets." Richardson[129] reached a like conclusion in 1937, and gives further details in his most recent publication.[130] The Bukit Kajang granite porphyry is composed of orthoclase, microcline, albite $An_{92}An_8$, and quartz, and subordinate, even rare, dark minerals. The marginal type has slightly more basic plagioclase, $Ab_{88}An_{12}$. Quantities are not stated, but apparently the albite is subordinate in amount to potash feldspars. Details are lacking on the feldspars of the dike rocks.

At the Kinsei Mine, Korea[131] "the deposit is a composite vein consisting of pegmatite, alaskite and quartz . . . as observed . . . underground . . . the earliest pegmatite veins being cut by an alaskite vein and lastly in turn by a typical quartz vein." Most of the gold values occur in the alaskite, and the pegmatites and quartz veins contain only a trace. The feldspar content decreases through the sequence pegmatite, alaskite, quartz veins, and is microcline throughout—albite is not even mentioned. This deposit is said to be typical of many throughout Korea, and is probably of late Cretaceous age. It appears to constitute a glaring exception to the generalizations suggested in this paper, but information is not available on the silver content of the ore, or the petrographic details of the post-Jurassic pre-Tertiary granitic rocks of Korea.

126 Barr, H. L., and Gardner, D. L.: A. I. M. E., Tech. Pub. 1187, 1940.
127 Gardner, D. L.: Oral communication.
128 Willbourn, E. S.: Rept. of Geol. Surv. Dept., Fed. Malay States, 1933.
129 Richardson, J. A.: Rept. of Geol. Surv. Dept., Fed. Malay States, 1937.
130 Richardson, J. A.: Rept. of Geol. Surv. Dept., Fed. Malay States, 1939.
131 Kato, T.: Japanese Jour. Geol. & Geog., XIII (1–2): 103–105, 1936.

Mushketov [132] in his sketch of the gold deposits of Russia makes it clear that most of them are genetically related to granitic rocks, but he is specific about the characters of these rocks in only one case, that of the Aiat deposit in the Verkh-Issetsk district which he relates to hypabyssal quartz albite porphyry. It may also be noted that the dikes associated with the gold deposits of Beresowsk are the original beresites, which are highly siliceous albite alaskites.[133]

SWEDEN.

Ödman [134] mentions that the commonest rock underground in Boliden is a keratophyre with dense groundmass and small clear phenocrysts of albite; but the origin of the ore is not assigned to any specific rock.

ENGLAND.

Despite its lack of gold production, England provides one of the most interesting cases in point: Brammall and Harwood's [135] detailed description of the gold-bearing Bittleford pegmatite from the Dartmoor suite. In all the analyses of the Dartmoor granitic rocks $K_2O > Na_2O > CaO$, except in this pegmatite, wherein $Na_2O > K_2O$. The age relations of the pegmatite are unknown, but it is clearly related to the Dartmoor suite on petrographic evidence. The Giant granite is cut by both the Blue granite and the Wittabarrow felsic rock. The data may be tabulated as follows:

	Bittleford Pegmatite.	Giant Granite.	Blue Granite.	Wittabarrow Felsic Rock.
Quartz	31.2	34.0	36.8	25.9
Orthoclase	14.5	22.3	26.2	48.1
Albite	37.7	25.4	24.4	21.7
	$Ab_{88}An_{12}$	$Ab_{82}An_{18}$	$Ab_{93}An_{7}$	$Ab_{95}An_{5}$
	Mo, Ag, Au	Mo	—	—
	Wet magma			Dry magma

[132] Mushketov, D.: In Gold Resources of the World, XVth Int. Geol. Cong., Pretoria, 1930, pp. 305–319.

[133] Tröger, W. E.: Spezielle Petrographie der Eruptivgesteine. Deutsch. Min. Ges. e V., 1935.

[134] Ödman, O. H.: Geol. För. i. Stockholm, Förh. Mar.–April, 1938, p. 123.

[135] Brammall, A., and Harwood, H. F.: Min. Mag. (London), 20: 39–53, 1923, and 201–211, 1924.

The differentiation proceeded toward the more potassic Blue granite, and although the later members contain more albitic plagioclase, the gold stayed in the fraction in which soda exceeded potash; the plagioclase is oligoclase, and silver exceeds gold in all but two assays.

SELECTION OF THE EXAMPLES.

The question may arise whether unconscious selectivity entered into the choice of the cases cited above. The search of the literature was admittedly undertaken to collect cases of gold deposits genetically related to albite-rich igneous rocks. Exceptions were sought and welcomed and it was soon noticed that they possessed features, outlined in the generalizations at the beginning of the paper, that segregated them from the deposits related to albitic rocks. Only those cases could be accepted for which there was (1) sufficient evidence of the genetic relationship between the mineralization and the igneous rocks, (2) sufficient petrographic data on the rocks, and (3) sufficient data on the silver content of the gold ores.

Sufficient evidence is rarely available to establish the genetic affiliation of an ore deposit with a specific igneous rock. Uncertain cases had to be rejected, which eliminated a great many of the references consulted.

Of the remaining references examined, few contain sufficiently precise petrographic data on the kinds of feldspars present. In the exceptional cases in which the plagioclase is specifically described, it is further necessary, for obvious reasons, to know the quantitative relations of the plagioclase to the potash feldspar, at least approximately.

Also, no deposit can be deemed an exception unless the gold-silver ratio is known. For example, the Korean deposits appear to constitute exceptions because they are associated with potash rocks, apparently devoid of albite, but if their silver content is high, they are not exceptions.

The limitations of space would hardly permit the enumeration of all the non-albitic deposits that are strongly argentiferous, or polymetallic, or contain abundant sulphides. For example, the

large number of epithermal gold deposits appear to be high in silver content, and associated with non-albitic rocks. Furthermore, their common association with volcanic rocks makes them the most difficult to assign to any one parental rock. At best they can be related only to an eruptive sequence or to a hypothetical intrusive at depth, and where the evidence is available these associated rocks are, in most cases, potassic.

Even in the examples quoted, the requirements are not fully met in all cases. It will be noted that in many the genetic relationship is little more than a logical suspicion. How many true exceptions lie hidden behind insufficient descriptions cannot even be guessed.

EXCEPTIONS.

However, a few examples have been found that appear to constitute real exceptions. The deposits of Hog Mountain, Alabama, are very similar to those associated with albitic rocks, but they occur in quartz diorite to which Park [136] relates them genetically, and no albite-bearing rocks are mentioned. This case, however, may not be a true exception, for Park believes that both the rock and the ore came from a mutual, ultimate source in the same magma chamber at depth and that the cooling of the quartz diorite had progressed far enough to permit its being fractured before the ore was introduced. It is therefore possible that the albitic differentiates existed, but were prevented from reaching the present surface.

Ducktown,[137] Tennessee, is an outstanding case of a non-auriferous, cupriferous ore deposit in which soda was an important constituent of the mineralization, particularly in the profound, pre-ore albitization. It may be significant that the few gold deposits of Tennessee are restricted to this same part of the State, but their genetic relationship to Ducktown, if any, is not clear.

Shasta County, California, provides a similar example. Here the pyritic copper deposits are believed by both Graton [138] and

[136] Park, C. F., Jr.: A. I. M. E., Trans., 115: 209–235, 1935.
[137] Ross, C. P.: U. S. Geol. Surv. Prof. Pap. 179, 1935.
[138] Graton, L. C.: U. S. Geol. Surv. Bull. 403B, 1910.

Seager[139] to be genetically related to abundant and widespread, highly sodic, alaskite intrusions. There are a few minor, late quartz veins of very low gold content.

Other pyrite-chalcopyrite deposits, without gold, but associated genetically with magmas that gave rise also to highly albitic rocks, are the Eustis mine, Quebec, Huelva, Spain, and those of the Rödhammer type in Norway.[140] Bastin[141] has shown that "aplites" of some of the Canadian copper-cobalt-nickel-silver ores were heavily albitized by an introduction of soda related to the mineralization. The zinc-lead deposits of Buchans,[142] Newfoundland, are believed to have come from the same magmatic source as the granite, that is locally high in albite and grades to quartz porphyry. About half the gold production of Newfoundland has come from these deposits,[143] and they may constitute an exception.

Another kind of possible exception may be mentioned; the pulaskite of Rossland, B. C., and the phonolite of Cripple Creek, Colorado, are both sodic rocks, but their exact relationship, if any, to the deposits considered in this paper, is not clear.

RECOGNITION OF THE TYPE.

Probably many examples of genetic association of albitic rocks and gold have escaped recognition; because (1) detailed field and microscopic work is generally essential, (2) the early albite may be so intensely altered that its original character is not readily recognized, and (3) albitic dikes may escape attention because in rare cases they may have approximately the grain size and color of dolerite.

GENERAL CHARACTERS OF THE DEPOSITS.

The gold deposits associated genetically with albitic igneous rocks show, in general, certain features in common. They are all hypothermal to lower mesothermal quartz veins. The quartz is

139 Seager, G. F.: Yale University doctorate dissertation, 1936.

140 Stevenson, J. S.: ECON. GEOL., 32: 350, 1937.

141 Bastin, E. S.: ECON. GEOL., 30: 715–734, 1935.

142 Newhouse, W. H.: ECON. GEOL., 26: 399–414, 1931.

143 Emmons, W. H.: Gold Deposits of the World, p. 107. McGraw-Hill Book Co., New York, 1937.

characteristic and needs no detailed description here. The mineralogy is simple, and the metallic minerals form a small part of the total ore. It may be summarized as follows:

Quantity.	Metallic Minerals.		Gangue Minerals.	
	Generally present in all cases.	Present in some deposits.	Generally present in all cases.	Present in some deposits.
Very abundant			Quartz Carbonates	Albite (in Au dike rocks.)
A few percent	Pyrite	Pyrrhotite Arsenopyrite	Tourmaline Sericite Chlorite	
Even smaller amounts of	Chalcopyrite Sphalerite Galena	Mo, W, (Bi, Sb)		Albite (in vein quartz)
Very small amounts of	Gold	Tellurides		

The absence of any other metallic minerals, particularly silver minerals, is conspicuous. The gold is generally associated with the chalcopyrite, sphalerite, and/or galena.

Features such as dip, length, width, and persistence with depth, are determined largely by structural controls and are independent of the kind of igneous rock genetically related to the deposits.

The paragenesis follows the general sequence (1) quartz, (2) silicates, (3) iron sulphides, (4) other sulphides, (5) gold, (6) carbonates. The minerals may each have formed over a period of time, or may appear in several generations, particularly the quartz, which is seldom present in only one generation. Complications arise particularly in the lower temperature end as might be expected from the general principle that the more feeble the conditions the more delicate is the reaction thereto.

WALL ROCK ALTERATION.

Some puzzling questions arise in the matter of wall rock alteration that deserve more detailed treatment than space will permit. Albitization ranges from nil to profound. Some authors attribute

it solely to the mineralizing solutions, and others to the initial character of the wall rocks. Its relation to sericitization is an enigma. In some deposits the wall rocks are sericitized and albite is deposited in the vein quartz, and in some others the wall rocks are albitized and sericite occurs in the veins. In many the albite is intensely sericitized,[144] and in others the albite may be unaltered, as if in chemical equilibrium with the mineralizing solutions. The albitization commonly precedes the sericitization, and both may be very intense as at the Toi mine,[145] Japan.

RELATED DEPOSITS.

The common occurrence of molybdenite and of scheelite in gold deposits of this type must have some significance. The affinity of tin, tungsten, and molybdenum, as well as gold, for the highly siliceous igneous rocks has long been recognized. As expressed by Spurr,[146] "finally there results the highly siliceous and aqueous residual magma from which pegmatitic quartz veins have crystallized. With the progressive increase of silica and water there is a corresponding increase of . . . tin, molybdenum, tungsten, and gold." These four metals are quite commonly thought of as a related group.

Hulin [147] believes, however, that the gold is independent of the other three. He groups the metals as Group I, SiO_2, W, Sn, Mo, Bi, and Group II, Fe, Zn, Pb, Cu, Ag, Au, etc., and concludes "that during mineralization Group I is independent of Group II, any time relations, or the absence of either group, being possible."

[144] Sericite is usually identified solely by optical means, and because of its fine grain size such identifications are often made largely by the "spot method." Yet on this basis of fact (?) the introduction of large quantities of potash may be inferred. The supposed soda mica, paragonite, has optical properties nearly identical with sericite, and although according to Winchell (Optical Mineralogy, 3d Ed., 1933, p. 270) "there is no conclusive evidence that such a mineral exists," it might well escape optical detection, particularly by the "spot method." There would seem to be little conclusive evidence that all so-called sericite is actually potash mica, and the geological evidence suggests that at least some of it might be soda mica. Certainly this kind of evidence of the abundant introduction of potash is not always unimpeachable.

[145] Kato, T.: Jap. Jour. Geol. and Geog., IX (1–2): 71–86, 1931.

[146] Spurr, J. E.: Econ. Geol., 2: 789, 1907.

[147] Hulin, C. D.: Econ. Geol., 34: 471, 1939.

No comprehensive study of the relationship of these metals to feldspar types seems to have been made, and cannot be attempted here, but a possible clue to their better understanding might arise from such an investigation.

Ferguson [148] concluded that the minute quantities of molybdenum in igneous rocks from Hawaii bore no relationship to the soda or potash content. The conditions of metallogenesis at Climax,[149] Colorado appear to have been quite hostile to soda, but albite is an abundant constituent of the molybdenite ores of Onslow township, Quebec.[150] Larsen and Ross [151] are not specific about the origin of the ore in the R and S Molybdenum Mine, New Mexico, but the principal rock is an alaskite porphyry containing 32 per cent quartz, 20 per cent orthoclase, and 47 per cent albite.

A brief survey of the literature on tungsten suggests that this element may occur commonly in association with potassic rocks, but may also be related to diorites, granodiorites, or quartz monzonites. The tungsten deposits of Burma [152] are related to the highly potassic Tavoy granite; but Kerr [153] describes tungsten-bearing, oligoclase pegmatites of Nevada in which "albite and scheelite were introduced at about the same time."

Ferguson and Bateman [154] state that "with one exception the content of K_2O is greater than that of Na_2O" in the analyzed igneous rocks related to tin deposits. The tin-bearing pegmatites of the Erongo [155] area of Damaraland, South-West Africa, have albite as a major constituent along with potash feldspar and quartz. All four elements, tin, tungsten, molybdenum, and gold occur together in a pegmatitic quartz vein at Outpost Islands,

148 Ferguson, J. B.: Am. Jour. Sci. (4), 37: 399–402, 1914.

149 Butler, B. S., and Vanderwilt, J. W.: Proc. Colorado Sci. Soc., 12 (10): 309–353, 1931.

150 Wilson, M. E.: Canada Geol. Surv., Mem. 136: 72, 1924.

151 Larsen, E. S., and Ross, C. S.: Econ. Geol., 15: 567–573, 1920.

152 Campbell, J. M.: Econ. Geol., 15: 511–534, 1920.

153 Kerr, P. F.: Econ. Geol., 33: 390–425, 1938.

154 Ferguson, H. G., and Bateman, A. M.: Econ. Geol., 7: 215, 1912.

155 Gevers, T. W., and Frommurze, H. F.: Geol. Soc. S. Africa, Trans., 32: 111–150, 1929.

Great Slave Lake, but Hawley [156] does not mention the character of the feldspar.

The association of tin with gold is the least common association among these four metals. Indeed, Berg [157] "believes that it is not possible to introduce the pyritic, arsenopyritic, quartz-gold veins at any point into the customary order of deposits: Sn, Bi, Cu, Zn-Pb, Ag-Sb, Hg. The gold-quartz veins with their transitions to pegmatite veins (ordinarily albite pegmatite) are of coordinate formation with the tin deposits, which also have their transitions to pegmatites (ordinarily orthoclase pegmatites). The difference between the pegmatite tin and gold veins is not one of zonal distribution but is one that is dependent on the constitution of the parent magma." Apparently the affinities may be expressed as:

ALBITE END
gold
molybdenum
tungsten
tin
POTASH END

But the whole matter, even the conclusions of the present paper with regard to gold, needs more abundant evidence.

In passing, it may be mentioned that three other valuable minerals appear commonly to be associates of albite, namely magnetite, corundum and emerald.

THEORETICAL CONSIDERATIONS.

The close relationship of some gold deposits, as well as tin, tungsten, and molybdenum deposits, to pegmatites, and the genetic relationship of some gold deposits to trondhjemites and alaskites, naturally leads to fundamental questions on the genesis of these rocks.

In 1926 Lindgren [158] published his paper "Magmas, Dikes and

[156] Hawley, J. E.: Univ. of Toronto Studies, Geol. Ser., No. 42: 53–67, 1939.
[157] Berg, G.: ECON. GEOL., 22: 132, 1927.
[158] Lindgren, W.: A. I. M. E., Trans., 74: 71–92, 1926.

Veins" in answer to Spurr's[159] book, "The Ore Magmas." These, together with the discussion[160] that followed constitute a summary of the best thought on the relationship between pegmatites and veins up to that time. Spurr championed the direct transition of pegmatites into ore-bearing veins; Lindgren dissented. In 1931 Tolman[161] reviewed thirty-nine cases of the gradation of quartz veins into igneous rocks, mostly pegmatites, without, however, considering the nature of the associated feldspars. Now the transition is widely accepted to be a fact, but only within certain limits.

Landes[162] reviewed the history of the concept, and concluded that only tin, tungsten, and molybdenum occur "with any consistency" as ore minerals in pegmatites. He emphasized the very silicic character of the magmas associated with these three metals, and goes on to say, "Most ore minerals, such as gold and sulphides, are derived from less acidic magmas (those that crystallize into granodiorite, monzonite, diorite, and varieties of these rocks)." He favors the view that pegmatites are less common in these rocks "because the intermediate magmas for some reason pass through but a very subordinate pegmatite phase before entering the hydrothermal stage. . . . During the latter, gold, sulphides, and similar ore minerals are deposited in whatever pegmatites are present, but mainly in hydrothermal veins in the overlying rocks."

The extensive differentiation and metasomatism involved in pegmatite formation is now widely accepted, through the work of Schaller, Hess, Landes, and others, and many examples have been given of the common progression toward an albitic end product. But the recent work of Maurice[163] has provided an example on a grand scale in which metasomatism is not considered to be a factor. It is probably significant that the deposits with which he deals are predominantly oligoclase pegmatites, not potash pegma-

159 Spurr, J. E.: The Ore Magmas. McGraw-Hill, New York, 1923.
160 Spurr, Lindgren, et al.: A. I. M. E., Trans., 74: 93–126, 1926.
161 Tolman, C.: Am. Min., 16: 278–299, 1931.
162 Landes, K. K.: Am. Min., 22: 551–560, 1937.
163 Maurice, C. S.: Econ. Geol., 35: 49–78, 158–187, 1940.

tites, and appear to be related to the granodiorite or trondhjemite stem; for Landes [164] says, "In my experience pegmatites are large and abundant only where they are offshoots of potash rich rocks (granite and syenite)."

No universally accepted theory of the origin of trondhjemites has yet been advanced, and their petrogenesis is at least as difficult as the problem of the anorthosites. The pegmatitic emanations and mineralizing solutions arising from the diorite, quartz-monzonite, potash-granite, syenite, potash-alaskite, potash-pegmatite group of rocks are quite different from those arising from the diorite, granodiorite, sodic granodiorite, trondhjemite, albitite, albite-alaskite group of rocks. The potassic group gives rise to potash pegmatites of great mineralogical complexity in which metasomatism is important and albitization is commonly profound. The sodic group gives rise to less common pegmatites of simple mineralogy in which metasomatism is unimportant and albite is primary rather than introduced.

Derivation of both these rock groups from a single type of parental magma, that is, according to the one magma theory of petrogenesis, would require a four-step alternation of the alkalies. First the concentration of soda as a normal result of plagioclase crystallization,[165] second the formation of potash feldspar, which is normally later than the plagioclase,[166] third the formation of the late albitization-stage albite, and fourth the manifestation of late potash in sericite. In brief, soda-potash-soda-potash. Evidently the first soda would have to be called upon to yield trondhjemitic rocks, for some trondhjemites are known to be replaced in part by later potash feldspar, and the second soda would have to be called upon to account for the albitized pegmatites in which the albite partially replaces the earlier potash feldspar.

Furthermore, the gold would apparently be required to split into two fractions to satisfy the one magma theory. The gold of the trondhjemitic association would have to leave the magma

[164] Landes, K. K.: Am. Min., *22*: 559, 1937.

[165] Bowen, N. L.: The Evolution of the Igneous Rocks. Princeton Univ. Press, 1928.

[166] Ross, C. S.: A. I. M. E., Lindgren Volume, p. 135, 1933.

shortly after the trondhjemitic material was forced out, the sericitization that not uncommonly follows such mineralization would be difficult to account for, and all this would have to occur prior to the stage at which the magma yielded the usual alkali silicic differentiates. The gold associated with the later albitizing emanations would have to remain in the magma until this later stage. It seems improbable that a four step alternation of alkalies would occur, or that the gold would split into two fractions, as the one magma theory would seem to require. Furthermore, no case was encountered in the present search of the literature in which trondhjemite intrusions were followed by gold-quartz vein deposition and both were subsequently injected by later albite-rich rocks.

It seems necessary to conclude that the two types of rock suites, with their respective pegmatites and gold deposits, were derived from two distinct magma types. The lack of clarity that has arisen from the loose usage of the terms granite and granitic should be avoided, and there is a need for more precise descriptions of the feldspars. A distinction should be made between orthoclase-alaskite and albite-alaskite, between orthoclase-aplite and albite-aplite, between granite pegmatites and trondhjemite pegmatites, and between ore deposits of granitic affiliations and those of trondhjemitic affiliations.

CONCLUSIONS.

Gold deposits of widespread occurrence, and a certain community of characteristics, have been ascribed to genetically related igneous rocks rich in albite. The examples cited indicate that (1) the albitic intrusives shortly preceded the mineralization, with soda and albite in some cases extending over into the early stages of vein formation; (2) the mineralizing solutions did not come directly from the albitic rock, but both were derived from a common magma parent below; and (3) in some cases the albitic forerunners exerted a structural control on the ore deposition.

A distinct difference appears to exist between the gold deposits related to albite-bearing rocks and those related to potash-feldspar rocks. The former contain little silver and the sulphides are

simple and not abundant, whereas the latter are argentiferous, polymetallic, or contain abundant sulphides.

The metallogenesis of these gold deposits is not readily explainable on the one magma theory of petrogenesis, and it seems necessary to conclude that the granitic and the trondhjemitic rock suites, with their respective pegmatites and gold deposits, were derived from two distinct magma types, and in either case the gold mineralizing solutions tended to be closely related to the highly albitic differentiates and left the parental magma shortly after them. Since the ultimate answers to the problems of metallogenesis are intimately bound up with the theories of petrogenesis, it is hoped that this paper will focus more attention on the nature of the feldspars of the rocks with which ore deposits are genetically related.

LABORATORY OF ECONOMIC GEOLOGY,
YALE UNIVERSITY,
NEW HAVEN, CONN.,
April 20, 1940.

STRUCTURE AND MINERAL ZONING OF THE PAILAVIRI SECTION, POTOSI, BOLIVIA.

DAVID LECOUNT EVANS.

ABSTRACT.

Mining has been continuous in the Cerro Rico de Potosi since 1545. The outstanding mineralization is confined to definite vein systems, the Mendietta, being the trunk system. A detailed consideration of structure emphasizes the *en echelon* arrangement as characteristic of all systems. Mineralization has been dependent on structure and on zoning, and not on favorable or unfavorable rock types. In the Pailaviri Section three periods of mineralization are indicated, and a consideration of these periods and their relationship to structure is a possible indication of what to expect in depth.

INTRODUCTION.

RECENT publications [1] on Bolivian tin deposits and on the Cerro Rico de Potosi have dealt with the deposit from the standpoint of mineralogy and history. The author here presents a description of a portion of the deposit based on general geology, with emphasis on the structural detail.

The studies on which the following observations are based were limited to the period of November 1933 to September 1935. No underground mapping was attempted above the Caracoles Level, but surface mapping was partly completed to the top of the hill. Additional information has been revealed by recent developments, but this is not available to the author.

Location.—The Cerro Rico de Potosi and the city of Potosi lie on the east slope of the Eastern Cordillera of the Bolivian Andes in the Department of Potosi, Bolivia (Fig. 1), at Lat. 19° 34′ 19″ S. and Long. 65° 32′ W. Potosi, 360 miles east of the Pacific, is reached by 483 miles of narrow gauge railway from Antofagasta, one of the Chilean ports of entry to this area.

[1] Ahlfeld, Friedrich: The Bolivian tin belt. ECON. GEOL., Vol. 31, 1936. Penhale, H. J. D.: Potosi Hill, Bolivia. The Min. Mag., London, Vol. 59, July, 1938.

The high altitude, 4060 meters for the city, and 4890 meters (16,000 feet) for the top of the cerro, accounts for the all-year cold climate, in this tropical latitude.

The Pailaviri Section is roughly considered to lie below the Caracoles Mine on the North side of the hill.

FIG. 1— INDEX MAP OF BOLIVIA AND POTOSI—

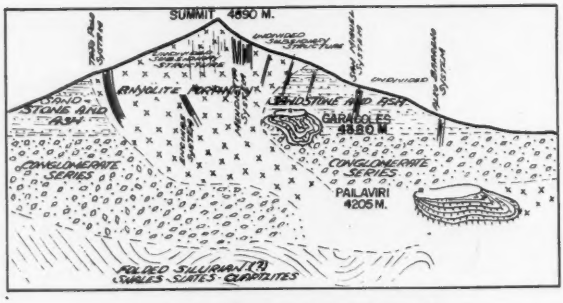


FIG. 2 — IDEAL SECTION OF CERRO RICO DE POTOSI, LOOKING SOUTH, SHOWING DISTRIBUTION OF ROCK TYPES AND MAIN VEIN SYSTEMS.

FIGS. 1 AND 2.

History.—The interesting history of Potosi may be briefly summarized as follows:

The deposit was discovered accidentally in 1544 by Diego Huallpa, a native llama herder of the nearby district of Huanchaca. Mining was well underway in 1545 and by 1572 the ex-

tremely high grade ore in the upper part of the hill was largely exhausted. The silver content of this high grade and upper zone has been reported as from 1500 to 9000 ounces per ton.

In 1580 the hill reached its peak production of 13,000,000 pesos [2] per year. Depletion of the high grade ore led to the introduction of the patio and amalgamation methods of recovery in 1590. These processes revived Potosi mining, and in 1610 a very elaborate system of lakes and ditches was completed to provide water for the mills.

Until 1810 the mines had been exploited by slave labor. The War of Independence (1810 to 1825) abolished the slave system and also the property rights and taxes, which had been, up to that time, the prerogative of the Royal House of Spain. The formation of large mining companies began in 1852 and deeper levels were mined for lower grade silver ores. In 1891 low silver prices forced many of the mines to change from silver to tin mining. The completion of a railroad in 1912 to Rio Mulatto, on the Antofagasta-Bolivia Railway, and the merger of many of the companies into a larger working unit in 1929, account for present day operation in this deposit.

Production.—One often hears the statement that this deposit was the "richest single concentration of silver on earth." Miller and Singewald [3] give 1,000,000,000 ounces as a minimum for the production, an estimate based on records of production from which the Royal House of Spain deducted its 1/5 part until 1580, and 1/10 part after that year. This, however, does not take into account the silver that has been "high graded," of which there is, naturally, no record. It is the general opinion that the total production would approach 2,000,000,000 ounces of silver. H. J. D. Penhale [4] places the value of tin and silver taken from the hill at not less than 400,000,000 pounds sterling.

[2] Soux, Louis: Private paper, 1935; the exact equivalent in dollars must remain a matter of speculation.

[3] Miller, B. L., and Singewald, J. T.: Mineral Deposits of South America. McGraw-Hill, 1919, pp. 122.

[4] Penhale, H. J. D.: *Op. cit.*

STRATIGRAPHY.

As early as 1637 the quartz monzonite porphyry or rhyolite porphyry of Potosi Hill was recognized and considered of the greatest importance. Friar Alvaro Alonzo Barba in his work El Arte de los Metalles, states,[5] "famous have been and are the vilaciques (blood red rhyolites) of this very rich hill of Potosi on account of the great abundance of silver that has been drawn from them." Jerman Zambrana in 1892[6] described the hill as "being composed of a volcanic rock, called rhyolite, which probably entered the shales of blue and gray color in Tertiary or pre-Tertiary times." Descriptions of Potosi by Miller and Singewald and Penhale cite the same relationships. Waldemar Lindgren[7] notes that "Cerro de Potosi is a relatively small mass of rhyolite porphyry or quartz monzonite porphyry, about two miles in length from north to south, which in places cuts Paleozoic slates while in other places it intersects and metamorphoses beds of plant bearing shale, believed to be of late Pliocene age."

Because of the generalities of all previously published papers, the writer desires to present in detail the column of Potosi hill. The rocks of the Cerro de Potosi are:

Surface deposits
Acid intrusives and possible flows
Shaly sandstone and ash series
Conglomerate series
Paleozoic sedimentary series

Paleozoic Sedimentary Series.—Bedded marine deposits of possible Silurian age are the basement rocks of the Cerro de Potosi. The extent of these formations cannot be known until the lower levels are opened. The series consists of interbedded shales, slates and quartzites, all steeply-dipping and contorted. Their age is based entirely on lithologic correlation with other rocks of

[5] Barba, Alvaro Alonzo: El Arte de los Metalles, 1637, trans. by Douglas, Ross E. and Mathewson, E. P. John Wiley and Sons, New York, 1923, pp. 31.

[6] Zambrana, Jerman: Monographia del Departamento de Potosi, por El Centro de Estudios de Potosi, Chap. 4, Part 3.

[7] Lindgren, Waldemar, and Creveling, J. G.: Ores of Potosi, Bolivia. ECON. GEOL., 23: 238, 1928.

determined age throughout Bolivia. It is reported by Miller and Singewald [8] that fossil determinations place these beds as Miocene or Pliocene. However, recent collections [9] have emphasized the early Paleozoic character of the formation. This series is capped unconformably by the Conglomerate series.

Conglomerate Series.—The basal portion of the conglomerate series is made up of boulders of rhyolite porphyry, shale, slate and quartzite, and was undoubtedly derived in part from the underlying Silurian (?) beds. The boulders show little rounding and vary in size from one-half inch pebbles to fragments two feet in diameter. Bedding is sparse in the bottom portion, but becomes more prominent in the upper although poor sorting is characteristic throughout. The conglomerate series grades conformably into the overlying sandstone-ash series.

Sandstone-Ash Series.—The sandstone and ash series was water deposited, but fossil plant remains suggest shallow water deposition. The flora, the only fossil evidence found so far in the hill, has been determined as of definite Pliocene age.[10]

As shown in Fig. 2 these beds are nearly horizontal. No attempt has been made to show in this section local variations of strike and dip or of the bending of beds near the veins.

Acid Intrusives (*and possible flows*).—Quartz monzonite or rhyolite porphyry occupies the center of the hill and has been considered as a solid intrusive plug. The author believes, however, that it may be in part intrusive and in part extrusive. This is shown by rhyolite boulders in the conglomerate series that in turn have been cut by rhyolite, indicating two ages of rhyolite. The sharp contacts between the rhyolite and older formations, the lack of extensive contact alteration, and existence of pronounced flow lines throughout the rhyolite mass, suggest that at least a part of the rhyolite is extrusive—a feature that should be considered in future detailed mapping. Additional support for extrusive rhyolite is given by the fact that on deeper levels, crosscuts into the supposed center of the plug have revealed only steeply dipping beds of

[8] Miller, B. L., and Singewald, J. T.: *Op. cit.*, p. 122.

[9] Clark, Edward: Personal communication.

[10] Miller, B. L., and Singewald, J. T.: *Op. cit.*, p. 123.

Silurian (?) slates and quartzites. However, whether flow or intrusive, the rhyolite cuts across all other formations.

Surface Deposits.—In addition to the talus and dumps that cover the greater part of the hill, the Pailaviri section is in part covered by an old stream channel, exposed to the east at the Santa Rita Mine and extending westward at the same elevation to the Cerro Chico (Fig. 3). Since this old channel has been worked for placer tin it is of economic importance.

STRUCTURE.

General.—The immense wealth of the Cerro Rico de Potosi has come from a series of fissure veins that cut northeasterly through the hill and, except for the Tajo Polo and Encinas systems, dip easterly. Although several strong fissure systems are present, the Mendietta system containing the Descubridor, Mendietta, Rica and Estano veins at the surface, and the Mendietta, Utne and Bronce veins in the Pailaviri Section, is considered to be the main trunk system of Potosi metalli· tion. This is based on the fact that most of the production of the upper levels was from this system, and it is also the most promising one disclosed by the deepest development. The fact that the Encinas system appears to have joined the Mendietta system downward, at about the Catalina level of the Pailaviri mine, and indications that the Tajo Polo will also be found to join the Mendietta at a lower level (Fig. 4) is supporting evidence for this interpretation.

Despite the thirty-four known veins, there has been a persistent attempt by investigators to group them into major systems of mineralization. Friar Barba in 1637[11] named the Centeno (called by some the Descubridor), Rica, Estano and Mendietta as the four principal veins of the hill. Zambrana[12] ignored possible systems and was satisfied with listing thirty-two veins, although he introduced a classification based on occurrence: (1) those exclusively in rhyolite, (2) those entirely in shales, and (3) those occurring in both. He considered the first two as the strong per-

[11] Barba, Alvara, Alonzo: *Op. cit.*, p. 62.

[12] Zambrana, Jerman: *Op. cit.*

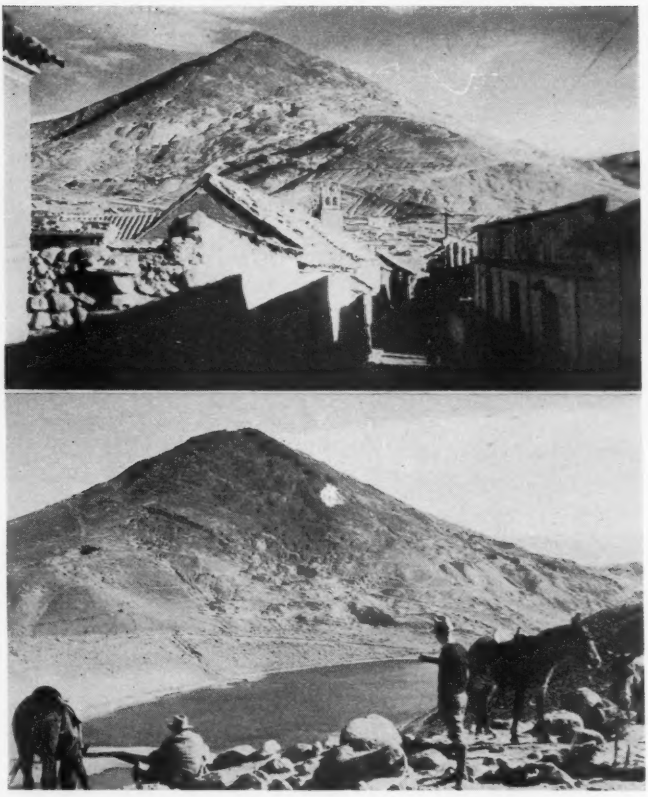


FIG. 3 (Upper). North slope of the Cerro Rico de Potosi with Cerro Chico in foreground.

FIG. 3 (Lower). Cerro Rico de Potosi. Sharp cut on near slope is Tajo Polo system at surface. Break at summit and line of cuts down central slope represents Mendietta system. In foreground one of many artificial lakes constructed in 1610.

sistent veins of the hill and the third of only slight significance. Subsequent mapping has shown that the Mendietta, Encinas, and Tajo Polo systems are not effected by changes in rock type. It

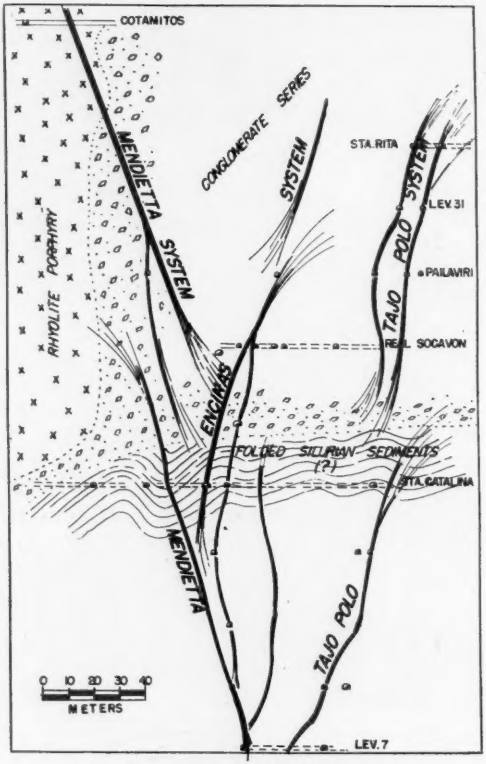


FIG. 4.—TYPICAL SECTION, FACING NORTH, SHOWING ECHELON CHARACTERISTICS AND RELATIONSHIPS OF VEIN SYSTEMS.

has also been shown that the San Miguel and Alko Barreno systems (described below) start in and die out in the same bedded rocks. Thus, changes in the enclosing rock formations have little effect on strength of the veins.

H. J. D. Penhale,[13] quoting from Miller and Singewald, shows, in section, that Tajo Polo, Encinas, Mendietta, Rica, Estano, Hernandez, and San Miguel veins are outstanding. Waldemar Lindgren [14] describes the following main veins: Tajo Polo, Mendietta, Rica, Estano, Bronce, Bolivia (probably means Bolivar), Hernandez, San Miguel and Asuncion. Louis Soux [15] lists thirty-four veins and considers Tajo Polo, Encinas, Rica, Bolivar and San Miguel the principal ones. Dr. Ahlfeld [16] gives little consideration to the structural control of the deposit, but does call the Tajo Polo the main trunk system of the mineralization. Despite the disagreements on the main subdivisions, there is general agreement on the importance of the Tajo Polo, Encinas and San Miguel systems, in which the author concurs. There is also agreement, in the more recent writings on Potosi, that the Mendietta vein can be followed continuously, except for en echelon offsets, from the surface to the deepest workings.

Recognition of the Descubridor, Rica, and Estano veins in depth is uncertain because of the inaccessibility of intermediate horizons, and lack of reliable maps but the author groups them, because of their position close to the Mendietta on the surface, with the Mendietta system. Reference to Fig. 5 will show that in this manner, the Bolivar, very strong at the Caracoles Level and considered by Soux a separate system, has been included under the Mendietta system. This also applies to other branches lying between the Mendietta and the Bolivar on the Caracoles Level. The following interpretations are possible for these three veins (considered main veins by Barba, Soux, Miller and Singewald), which are not found in depth: (1) That these veins adjacent to the Mendietta are a part of that system, but die out in depth. (2) That they branch from the Mendietta in unmapped horizons above the Pailaviri section of the deposit. Neither interpretation forbids the consideration of a broad Mendietta system that includes these near-surface subdivisions.

[13] Penhale, H. J. D.: *Op. cit.*, p. 15.
[14] Lindgren, Waldemar: *Op. cit.*, p. 239.
[15] Soux, Louis: *Op. cit.*
[16] Ahlfeld, Friedrich: *Op. cit.*

The Alko Barreno, the most westerly developed vein, appears generally to have escaped consideration, but is of sufficient strength and importance to deserve the classification of a major vein system.

On the basis of underground mapping in the Pailaviri section, the author believes that the veins can be grouped under five main systems: the Tajo Polo, Encinas, Mendietta, San Miguel and Alko Barreno. The last two reach the Pailaviri horizon as strong fissures but changes of mineralization with depth make them of little value at this horizon. However, records of prŏduction from higher levels, and the strength of the fissures, are sufficient evidence to class them both as major systems although they are of less importance than the other three systems.

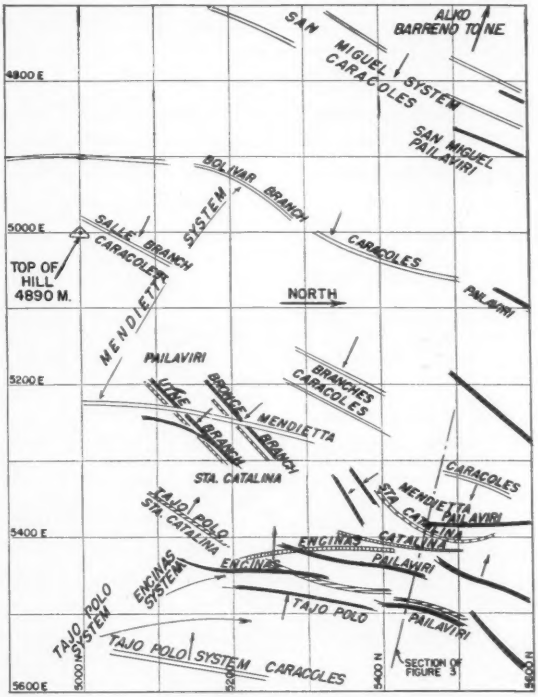
The area involved in this structural pattern has an east-west length of 1.2 km., and at least some ore can be traced along the strike of these veins for 1.35 kilometers. The hill has in part been mined to a depth of 800 meters below its summit, and commercial possibilities are believed by some to extend considerably below that depth.

Fig. 4 gives the relationship of the productive vein systems of the Pailaviri section. The Encinas and Tajo Polo dip westerly into the Mendietta system (main trunk vein) with which the others appear to be merging with depth.

Detail.—Detailed mapping has disclosed that the Potosi veins have a distinct en echelon structure to at least that part of the Cerro lying below the Caracoles Level. It is not known if this type of structure extends from the Caracoles Level to the surface. However, it is improbable that such an outstanding characteristic should change abruptly in vertical section at any given horizon. The en echelon character of the three vein systems is clearly shown by Fig. 4. The Mendietta vein, changing strike with depth as it breaks into the Bronce and Utne branches, is also part of this picture.

In both plan and section each structural system can be divided into a succession of discontinuous veins, separated from each other by gaps of country rock containing weak stringers of min-

eralization. Drifting on any one of these veins reveals that a solid sulphide will eventually pass into a series of widely spaced, mineralized stringers whose strike curves away from the strike



COMPOSITE PLAN MAP OF VEIN SYSTEMS

FIG. 5 PAILAVIRI SECTION

of the system. Any advance away from the curve of these stringers will intersect the set of stringers or "horsetails" belonging to the next solid mass of mineralization. This general relation holds both horizontally and vertically.

Since the strikes of the various vein systems appear to continue across the hill without regard to the porphyry mass, this is considered evidence of regional compressional shearing. It is believed that by such a means a northeast-southwest pattern was developed with its greatest expression in the Mendietta System.

MINERALIZATION.

General.—The ores of the Cerro de Potosi can be divided into the upper oxide zone, the lower oxide zone, the upper sulphide zone, and the lower sulphide zone. The oxide zones are known only incompletely. The upper oxide zone was characterized by both silver and tin mineralization. W. H. Emmons [17] states:

> At Potosi, Bolivia, where sulphide ores of silver carry stannite and cassiterite, the silver is greatly concentrated near the surface. Possibly there has been some secondary concentration of tin. . . . Evidently the outcropping was very rich in silver, for it is said to have been discovered by an Indian who built a fire above the ore and found streamlets of silver in its ash. Enormous bodies of altered ores (PACOS) were worked, their valuable content being mainly in horn silver and native silver. . . . Tin and silver appear to have been segregated in the upper parts of the lodes for Wendt states that the early miners of silver left tin deposits that were subsequently removed. Much of the tin ore was wood tin, and like silver it appeared to have been concentrated in the oxide zone. . . .

In the writer's opinion, however, the upper concentration may not have been due to oxidation and enrichment, but possibly to two surges of mineralization, one essentially tin bearing and the other rich in silver. A mixture of oxide and sulphide ores characterizes the lower oxide zone, which grades into the underlying sulphide zone.

Of the sulphide zone (one division) Lindgren and Crevelling [18] state: "The ores are complex, rather fine grained, and massive aggregates, chiefly consisting of quartz, pyrite, cassiterite, sphalerite, andorite, chalcopyrite, and other minerals. The tin is contained in cassiterite and stannite, the latter quite abundant in places. The silver is contained in tetrahedrite, andorite, ruby silver and matildite." Bismuthinite and wolframite were not mentioned.

[17] Emmons, W. H.: Enrichment of ore deposits. U. S. Geol. Surv. Bull. 625: 400, 1917.

[18] Lindgren, Waldemar, and Crevelling, J. G.: *Op. cit.*, p. 244.

An abrupt change in the mineralization of the Tajo Polo vein below the Pailaviri level indicates a lower sulphide zone. This change is characterized by an increase in stannite, a decrease in cassiterite, more abundant chalcopyrite, prominent bismuthinite and wolframite and the practical disappearance of the complex silver minerals that are so common above. This change of mineralization in depth in the Tajo Polo system, and its downward trend toward the Mendietta system, suggests that the Mendietta system may likewise disclose at greater depth a similar downward change with decreasing cassiterite and increasing pyrite and stannite.

Detailed Mineralogy.—Detailed field observations, aided by some microscopic study have suggested three distinct periods of mineralization as follows:

1. An initial period of pyrite, arsenopyrite and quartz of contemporaneous deposition, and coincident with wolframite and bismuthinite at greater depth.
2. A later period of quartz, cassiterite and pyrite.
3. A final period of quartz, carrying chalcopyrite and stannite at depth, but with chalcopyrite, stannite and the complex silver-bearing sulphides at higher levels.

These sequential periods of mineralization are in disagreement with the observations of Dr. Ahlfeld,[19] who attributes Potosi mineralization to but one period of activity, and believes that changes in depth are due to differences in temperature and pressure, which cause the various components to unmix from a colloidal state. The basis for this belief is his observation of a colloform arrangement between the various sulphides and cassiterite which the author did not observe and has been unable to substantiate. There is a definite banding in fissure fillings but study has revealed that such banding is due to repeated reopening and mineralization.

The three periods of mineralization compare favorably with five phases described by Lindgren and Crevelling,[20] as follows: "One may divide the period of deposition (1) pyrite, arsenopyrite, cas-

[19] Ahlfeld, Friedrich: *Op. cit.*

[20] Lindgren, Waldemar, and Crevelling, J. G.: *Op. cit.*, p. 254.

siterite phase; (2) sphalerite, chalcopyrite, stannite phase; (3) tetrahedrite and andorite phase; (4) ruby silver, matildite and jamesonite phase; (5) the phase of supergene sulphides and the oxidation products."

CONCLUSIONS.

A detailed study of the structure and mineral zoning indicates that these are the important features of the distribution of Potosi mineralization, and that differences in rock formations have exerted only a minor influence.

Structural systems are clearly defined in the Pailaviri mine and it is believed that mapping of the upper mines in detail would show that this same structural simplicity would extend upward to the surface.

Preliminary observations on mineral sequence are included to indicate the intimate relationship between structure and zoning, and the importance of both in the consideration of future ore possibilities at greater depth.

ACKNOWLEDGMENTS.

The author is indebted to Dr. B. S. Butler of the University of Arizona, to Edward Clark of Drury College, Missouri, and to Mary Catherine Trueblood Evans for helpful criticism. The author has also appreciated the suggestions and advice of Dr. J. W. Vanderwilt.

CLIMAX, COLORADO,
February 24, 1940.

THE ZINC AND LEAD DEPOSITS OF SHAWANGUNK MOUNTAIN, NEW YORK.

ALBERT IRWIN INGHAM.

ABSTRACT.

The lead and zinc ores of Shawangunk Mountain, New York, were among the earliest worked in this country, but the mines have been inactive in recent years. The ores which are all found in the Shawangunk Grit occur along bedding planes, in cross fissures and brecciated zones. They are considered to have been deposited by solutions of magmatic origin.

THE lead and zinc deposits described in this paper are located on Shawangunk Mountain near Guymard, Summitville, and Ellenville, in Orange, Sullivan, and Ulster Counties respectively (Fig. 1).

Shawangunk Mountain is located in southeastern New York and extends northeasterly from Port Jervis, Orange County, to High Falls in Ulster County. Its highest part (2300 ft.) is near Maratanxa Lake, southeast of Ellenville. The Walkill Valley borders it to the east, and to the west it is separated from the Catskill Plateau by the Rondout Valley. The mountain, with sharp eastward-facing cliffs, owes its elevation and form to the resistant grit that caps the summit. The southern extension of Shawangunk Mountain into New Jersey and Pennsylvania is Kittatinny Mountain.

HISTORY.[1]

The lead and zinc mines of southern New York are among the earliest ones worked for these metals in the country. Tradition has it that the ores were smelted by Indians and hunters to make bullets.

As early as 1820 the Ellenville mine was opened, and in 1840

[1] History of the mines was obtained from Mather: Geology of New York, Pt. I, 1st Geol. Dist., 1843. Newland, D. H.: Mineral resources of New York State. N. Y. State Mus. Bull. 223–24: 296, 300–6, 1919.

it was being worked by the North American Coal and Mining Company whose operations reached their peak from 1853 to 1857. Subsequently, it was intermittently worked and in 1917 it was dewatered and re-examined.

The Shawangunk mine, near Summitville, was actively worked from 1830 to 1840 and at various times later. The ore was

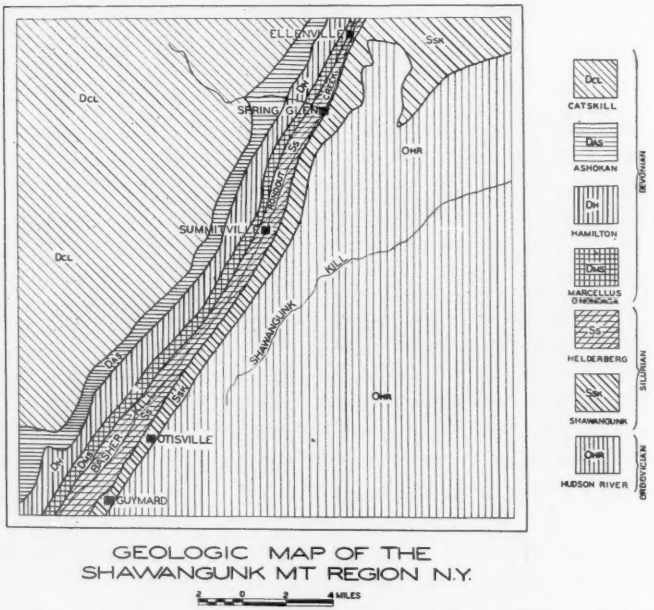


FIG. 1. Geologic map of Shawangunk Mountain region, New York.

treated at a smelter located at the base of the mountain on the Delaware and Hudson Canal. In 1917 operations were resumed for a short time. Although it has been abandoned for over twenty years, the workings are still mostly accessible.

The Guymard mine, located near Guymard, Orange County was worked from 1863 to 1870, and for a time in the eighties. Here, too, an attempt was made to reopen it in 1917.

These three mines were the most important ones in the district. A number of smaller ones were also worked, among them an interesting one near Spring Glen where an adit enters the mountain under a waterfall. Another, the Ulster mine, opened in 1836, is located near the Ulster-Sullivan County boundary line on Shawangunk Mountain seven hundred feet above the valley.

GENERAL GEOLOGY.

Stratigraphy.—The geologic section in the Shawangunk Mountain area [2] is as follows:

Devonian		
Helderberg	400	Ft.
Silurian		
Manlius limestone	70	"
Cobbleskill cement beds	30	"
Binnewater sandstone	50	"
High Falls shale	75–80	"
Shawangunk conglomerate	250–300	"
Unconformity		
Ordovician		
Hudson River series	2000	"

Although the formations above and below the Shawangunk are present in the area, only the Shawangunk contains ore.

The Shawangunk formation, which rests unconformably on the Hudson River shales, varies from a siliceous sandstone to a coarse conglomerate; however, the quartzitic phases are uncommon and of local distribution, most of the formation being a conglomerate. The color of the rock is various shades of white, gray, red, or green. The pebbles are of quartz, well rounded, with an average diameter of less than one half inch. The bedding is massive, averaging several feet, and the rock is relatively impervious and resistant to weathering. Thin shale partings make up a small part of the formation, and near the top the conglomerate becomes pyritiferous. Its thickness increases to the south, and in the Ellenville section it is about 300 feet.

Structure.—The Shawangunk Mountain area is marked by both simple and complex structures. According to Berkey,[3]

[2] Berkey, C. P.: Geology of the New York aqueduct. N. Y. State Mus. Bull. 146: 55, 1911.

[3] *Op. cit.*, p. 31.

Shawangunk range and Rondout Valley form a transitional unit from complicated structural and tectonic conditions of the southerly districts to the uniform and almost undisturbed strata of the Catskills. Its southeasterly half is a mountain ridge partaking of extensive folding and faulting and represented by the thick and very resistant Shawangunk formation forming high eastward-facing cliffs. Toward the northwest these disturbances diminish, the strata gradually pass deeper beneath a great succession of shales, limestones and sandstones of the Helderbergian series and a broad valley is eroded in these softer portions.

Shawangunk Mountain is a northwest-dipping monocline, probably the northwestern limb of an anticline that has been breached by erosion. To the north, in the vicinity of High Falls, only a small portion of the southeastern limb remains. Superimposed on the monocline is a series of anticlines and synclines.[4] The character of the folding and the presence of thrust, normal, cross and bedding faults, development of cleavage, and the presence of an unconformity at the base of the Silurian, indicate a complex structural history.

None of the large strike faults that have been noted in this general region [5] cut the Shawangunk formation.

The ore body in the Shawangunk mine follows a crushed zone along the bedding planes, but numerous small, mineralized fractures extend out from it. The beds dip 40° NW, and the shear planes have a slightly steeper dip.

ORE DEPOSITS.

Mode of Occurrence.—The only deposit that could be examined was the Shawangunk mine, as the others are inaccessible. However, comparison of the writer's observations of the mode of occurrence of the ore in this mine with observations made by others some years ago in mines then open, indicates that the occurrence of the ore is similar in the different ore bodies.

The ore in the Shawangunk mine occurs: (1) along bedding planes of the grit (Fig. 2); (2) in fissures that cross the bedding planes; (3) in brecciated zones (Fig. 3); and (4) in minor disseminations. The brecciated zone in this mine is parallel with

[4] Darton, N. H.: Geology of Ulster County. N. Y. State Mus. Rep. 47: 542, 1894.

[5] Berkey, *op. cit.*

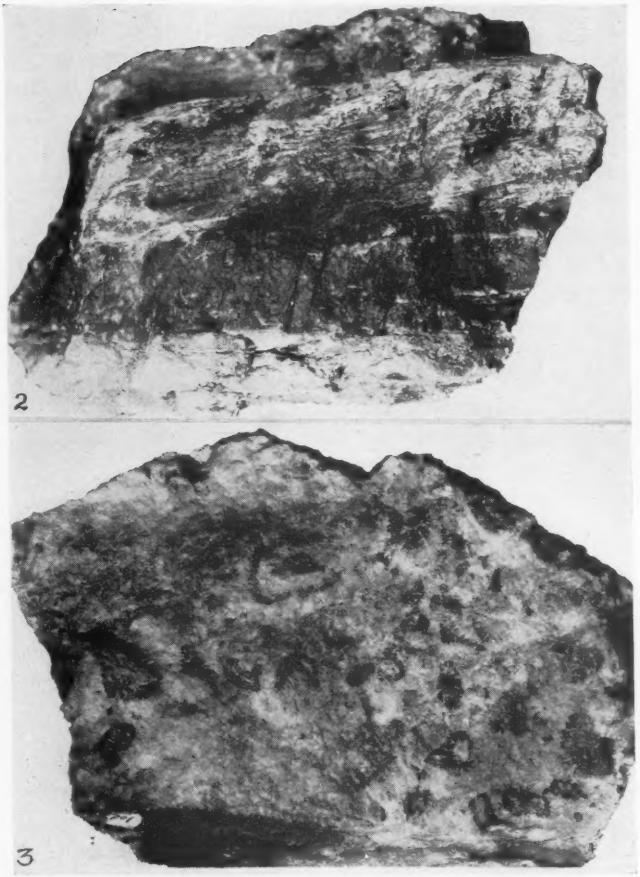


FIG. 2. Band of sphalerite deposited along bedding plane of Shawangunk Grit.

FIG. 3. Specimen of ring ore. Rounded fragments of wall rock surrounded by quartz and sphalerite.

the bedding of the country rock and has been formed by movement along the beds; this type is the most extensive in length and width. The thickness of the veins varies from a fraction of an inch up to five feet. However, the individual veins pinch out in short distances. The cross veins are rarely more than six inches wide and only a few feet in length. They developed during faulting as tension cracks that make an acute angle with the shear zone.

Fig. 2 shows a vein of solid sphalerite deposited parallel to the bedding planes of the country rock. That post-mineral deformation took place is proven by the development of cleavage, which is well shown in the sphalerite.

Fig. 3 is a specimen showing ring or cockade ore. Rounded fragments of the wall rock are surrounded by quartz and sphalerite. In some of the fragments it appears that the quartz was deposited at the same time with the quartz overlapping the sphalerite. There has been some replacement of the brecciated fragments by sphalerite.

Structure of the Veins.

A portion of the ore body in the Shawangunk mine shows a brecciated zone of considerable extent. Movement along the bedding planes has crushed the beds on either side of the fault so that fragments of wall rock are found in the quartz veins along the mineralized zones. The fragments, both angular and rounded in shape, vary in size from a quarter inch to as much as eight inches, the average size being two to three inches. The mineralizing solutions, moved into this disturbed zone and deposition of the minerals took place around the brecciated fragments, quartz being the most abundant. One vein is three feet wide and is composed almost entirely of solid quartz with some sphalerite deposited around fragments of the country rock. Here and there small vugs occur in the quartz between the breccia fragments. The ore gives one the impression that the country rock consisted of unsupported fragments, but this is incorrect. However, some fragments were found completely surrounded by crystallized quartz, due probably to the fact that as the quartz grew around

them it pushed them away from adjoining fragments with which they were originally in contact.

In the Shawangunk mine it was observed that the sphalerite was more abundant near the footwall than the hanging wall.

Mineralogy of the Ores.

The principal minerals found in the ore are sphalerite, galena, chalcopyrite, and quartz. Pyrite is scarce. Some secondary copper minerals, such as covellite and the carbonates azurite and malachite, have been formed by alteration of the chalcopyrite. Minor amounts of zinc and lead carbonates and sulphates were observed as coatings on the sphalerite and galena. Whitlock [6] has reported brookite from material collected at Ellenville, and Nason [7] found rutile in the same locality. Mather,[8] by cupellation of the galena, obtained a small amount of silver. Oxidation of the iron and copper sulphides has produced limonite which appears as coatings on some of the ores and as small stalactites in the Shawangunk mine.

In general, the proportion of sphalerite to galena varies not only from mine to mine, but even in the same mine. Sampling of the ore [9] from the Shawangunk mine showed the following percentages: Iron—3.54; lead—12.89; zinc—20.73.

Sphalerite.—This is the most abundant ore mineral. It is dark brown in color, and coarsely crystalline, more rarely foliated. In most cases it is in intimate contact with galena and quartz. It may occur in cavities around earlier quartz, as a vein filling (Fig. 2), as a ring or collar around breccia fragments or even replacing them (Fig. 3), and as disseminations in the country rock. In a few instances sphalerite inclusions were noted in clear quartz. A few thin crusts of alteration products of the sphalerite were observed.

Galena.—This is next in abundance to sphalerite, and commonly occurs intergrown with it, but was also observed as coarsely crys-

[6] Whitlock, H. P.: Personal Communication.

[7] Nason, F. L.: Economic geology of Ulster County. N. Y. State Mus. Rep. 47, 1894.

[8] Mather, W. W., *op. cit.*, p. 361.

[9] Newland, D. H.: *op. cit.*, p. 302.

talline, isolated masses. As previously noted, it is reported to be argentiferous. Little was found in the Shawangunk mine at the time of the writer's visit, but large masses are reported as having been found in the earlier years of the mine's history. The galena may replace both sphalerite and quartz.

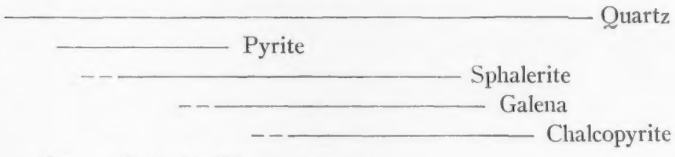
Chalcopyrite.—This mineral may replace quartz, sphalerite and galena, and in places occurs in rather massive form. In the Ellenville mine there have been found some well developed crystals, generally in cavities and attached to the earlier quartz. The sphalerite may show small grains of chalcopyrite in sphalerite, unevenly distributed, and showing no relation to structural lines of the sphalerite. This feature has been noticed at other localities and has been ascribed by Buerger [10] to unmixing, although here in cases it looks much like replacement. In some places the chalcopyrite is altered to covellite.

Pyrite.—This is rare, and its relation to the other sulphides is uncertain, although it appears to have been formed during the early stages of mineralization and soon after the quartz formed, and may in part replace it.

Quartz.—The gangue mineral of the ore is quartz. It may occur as massive quartz filling fractures (Fig. 3), and as crystals on the walls of cavities, or surrounding fragments of the country rock. The Ellenville mine has provided many collections with fine groups of quartz crystals. A curious feature of many of these crystal groups is that they show a later coating of drusy quartz. In a group of crystals this generally occurs only on those sides which face in the same direction.

Paragenesis.

The order of development of the minerals is illustrated by the diagram given below:



[10] Buerger, M. J.: Am. Min., 19: 529, 1934.

Examination of the diagram shows that the minerals have been deposited in an overlap relationship. The author prefers to use the term "overlap" in accordance with Bastin, Graton, et al.[11] rather than to speak of partial simultaneity or contemporaneous deposition.

The period of mineralization began with the deposition of quartz, and this mineral came out more or less continuously throughout the entire sequence. Not only is it the first mineral to coat some of the brecciated fragments (Fig. 3), but it is also found upon the last sulphide to form, chalcopyrite. Its relationship to sphalerite and galena suggests that it was being deposited at the same time as these two minerals. Pyrite started to come out shortly after the initial deposition of quartz and replaced the latter. Sphalerite commonly replaces quartz, and both sphalerite and quartz are replaced by the galena. Chalcopyrite was the last sulphide to form and has replaced all minerals formed previously to it.

ORIGIN.

The lead and zinc ores are considered to be of hypogene origin, deposited by rising magmatic waters in the telethermal zone. Although the nearest igneous rocks known are fifteen miles from the Shawangunk Mountain area, the evidence presented by the deposits suggests the presence at depth of a magmatic source for the ore-bearing solutions.

A number of lines of evidence substantiate the belief that the ore has had a hydrothermal origin. The localization of the ore along fracture zones in the grit suggests that the solutions have risen from below. The grit, rather impervious to solutions, would hardly permit descending solutions of any extent to be active in solution, transportation, and deposition of the metals. The large quantities of coarsely crystalline quartz, usually indicate hypogene solutions. Lindgren[12] says that in supergene sulphide deposition quartz is rare as a gangue mineral. The presence of silver in the galena suggests a hydrothermal rather than a meteoric

[11] Bastin, Graton, et al.: ECON. GEOL., vol. 26, no. 6, 1931.
[12] Lindgren, W.: Mineral Deposits, 4th ed., 1933, p. 826.

origin. Evidence of zoning noted by Ihlseng,[13] who found that the Ellenville deposit decreased in lead content at depth and increased in zinc, is additional support for a magmatic source of the ores. Then too, evidence against a meteoric origin for the lead deposits of southeastern Missouri, as noted by Tarr,[14] is also applicable in this deposit.

ACKNOWLEDGMENTS.

The author wishes to acknowledge the criticisms of Professors H. Ries and C. M. Nevin. Thanks are also due to J. S. Brown, P. Edwin Clark, T. M. Hills, P. F. Kerr, and D. H. Newland, for the loan of specimens collected from these mines in the past.

CORNELL UNIVERSITY,
GEOLOGY DEPARTMENT,
April 10, 1940.

[13] Ihlseng, A.: Eng. and Min. Jour., 1903, p. 630.
[14] Tarr, W. A.: ECON. GEOL., 31: Dec. 1936.

STATE MINERAL SURVEY IN ARKANSAS.

GEORGE C. BRANNER.

ABSTRACT.

A State Mineral Survey project was initiated in Arkansas on January 7, 1938, by the Works Progress Administration under the sponsorship of the Arkansas Geological Survey, and is now continuing.

A study is being made of easily identifiable and accessible minerals, and of ground and surface waters. Laboratories have been constructed and equipped to make mineral and water analyses and to prepare and fire clay samples.

Approximately 23,074 square miles, or 42 per cent of the area of the state, was surveyed to November 30, 1939. The total cost to all participants up to that date was $623,053. The average cost per square mile surveyed was $27.10.

A maximum of 663 persons was simultaneously employed on the project, and 1,229,114 man hours were used to November 30, 1939. The average labor per square mile was 53.2 man hours. At present 376 workers are employed, 35 of which are non-relief and 341 relief.

A large amount of valuable data has been collected and is being organized for publication. Results seem to justify the conclusion that untrained personnel can be successfully utilized to gather data on mineral resources and to collect mineral samples, provided the individual tasks are reduced to relatively simple and routine procedures and the supervision is competent. The greatest value of a survey of this character appears to lie in its application to specific sampling and testing programs.

INTRODUCTION.

THE State Mineral Survey project initiated in Arkansas by the Works Progress Administration (now Works Projects Administration) and sponsored by the Arkansas Geological Survey was designed to utilize the unusual labor and " white collar " employee facilities made available by the W.P.A., for the purpose of examining the areas within the state believed to be most favorably endowed with valuable minerals. The Survey program provided for determining the location and extent of mineral deposits and ground waters, and of the composition and value of these. Pro-

vision was also made for the compilation and publication of the information secured.

As the relief personnel carrying on this work have little or no technical training, field examinations are confined to easily identifiable rocks and minerals, and to surface and ground waters only in so far as they can be sampled by simple methods. Furthermore, cost considerations make it desirable that deposits examined be readily accessible. By utilizing the assistance provided in the manner indicated, a large amount of factual data is being accumulated.

SCOPE OF WORK.

The Arkansas State Mineral Survey was authorized to examine 32,666 square miles, or 61 per cent of the 53,335 square miles which make up the area of the state. The areas examined were selected for their probable mineral values and accessibility. Fifty-two of the 75 counties of the state, an area of 32,666 square miles, were included in the project and, of that area, 23,074 square miles, or about 71 per cent, had been examined to November 30, 1939. Field work is continuing at present in 32 counties. Work has been temporarily suspended in 14 counties and has not been begun in six others as a result of reductions by the W.P.A. in the number of workers allotted to the project.

Approximately 40,000 mineral samples have been submitted to the state laboratory for identification or analysis. After identification, about 8 per cent are retained for partial or complete analysis. Some 15,000 water samples have been collected from streams, wells, and springs for partial analysis and, in certain cases, for complete analysis. Complete water analyses are made only of certain selected samples.

In addition to the routine mineral and water surveys being made, individual drilling projects have been completed in areas containing limestone and bauxite. The limestone investigation resulted in the discovery of a buried body of Tertiary limestone containing some 3,500,000 tons of rock, which is to be utilized for the production of agricultural lime. The bauxite investiga-

tion made it possible to estimate the tonnage of a bauxite deposit of some size, located on state property. Plans for leasing this deposit are being considered. A third drilling project is under way in a gypsum area and two clay boring projects have been started. A special investigation of lead and zinc ore reserves has been completed and an investigation of manganese ore reserves is under way. It is anticipated that a marble sample and polishing project will be begun at an early date.

PROJECT COSTS AND LABOR.

From January 7, 1938, to November 30, 1939, a period of nearly 23 months, a total of 1,229,114 man hours had been used on the project, and the total labor cost to the W.P.A. in this interval was $557,837. Contributions by the sponsor and by county and independent agencies totaled $45,216, making an aggregate expenditure of $623,053 for the period indicated. The maximum number of W.P.A. workers employed on the project at any time was 663. The unit supervision and labor is shown in Table 1, and the unit supervision and labor cost, together with the unit cost of supplies and travel, in Table 2.

Total costs are shown in Table 3. Due to the variability of physical factors in the counties surveyed, substantial variations exist in the county unit cost and unit labor. The maximum and minimum unit county cost and labor figures are as follows:

	Maximum per Sq. Mi.	Minimum per Sq. Mi.	State Average per Sq. Mi.
Cost	$ 49.30 (Pulaski)	$10.93 (Sevier)	$27.10
Man hours	108 (Ouachita)	25 (Sevier)	53.20

Variable factors include topography, forestation, road conditions, and type of work undertaken. For example, the investigation of counties in which clay deposits occur requires the boring of holes with hand augers. This consumes much more time than is required for routine field investigations.

TABLE 1.

MAN HOURS CONSUMED IN SUPERVISION AND LABOR, FROM JAN. 7, 1938, TO NOV. 30, 1939.

	Total Sections	Number Sections Worked	Man Hours Consumed			Average Man Hours Consumed per Section		
			Supervision	Labor	Total	Supervision	Labor	Total
Active counties, 32	23,380	19,381	102,200	872,972	975,172	5.3	45.0	50.1
Suspended counties, 14	9,286	3,693	17,428	150,774	168,202	4.6	40.9	45.5
Central office	—	—	23,200	62,540	85,740	1.0	2.7	3.7
Total	32,666	23,074	142,828	1,086,286	1,229,114	6.2	47.1	53.2

TABLE 2.

COSTS, FROM JAN. 7, 1938, TO NOV. 30, 1939.

	Number Sections Worked	W. P. A. Expenditures					Miscellaneous Contributions [1]	Grand Total Costs	Average Cost per Section			
		Supervision			Labor	Total			Supervision	Labor	Misc. Contributions [1]	Total
		Salaries	Travel	Total								
Active counties, 32	19,381	$79,362.08	$27,551.88	$106,913.96	$332,517.85	$439,431.81	$25,840.60	$465,272.41	$5.52	$17.18	$1.33	$24.00
Suspended counties, 14	3,693	13,250.35	5,853.58	19,103.93	57,017.94	76,121.87	5,635.99	81,757.86	5.18	15.50	1.53	22.21
Central office	—	18,370.58	4,854.27	23,224.85	30,058.34	62,283.19	13,739.21	76,022.40	1.02	1.70	.60	3.16
Total	23,074	110,983.01	38,259.73	149,242.74	428,594.13	577,836.87	45,215.80	623,052.67	6.47	18.60	1.96	27.10

[1] Supplies, rent, utilities, miscellaneous salaries.

TABLE 3.

TOTAL EXPENDITURES FROM JAN. 7, 1938, TO NOV. 30, 1939.

	W. P. A. Expenditures	Sponsor's Contributions	Independent and County Contributions	Total
Labor	$428,594.13	—	—	$428,594.13
Total supervision and travel	149,242.74	—	—	149,242.74
Miscellaneous contributions	—	$13,739.21	$31,476.59	45,215.80
Total	577,836.87	13,739.21	31,476.59	623,052.67

ORGANIZATION.

To carry on the work of the survey, five related lines of activity have been organized; namely, administration, field surveys, testing, maintenance of records, and preparation of reports. The control plan is shown in Fig. 1.

In order to permit the proper supervision of field work and to establish a chain of responsibility, the counties authorized for

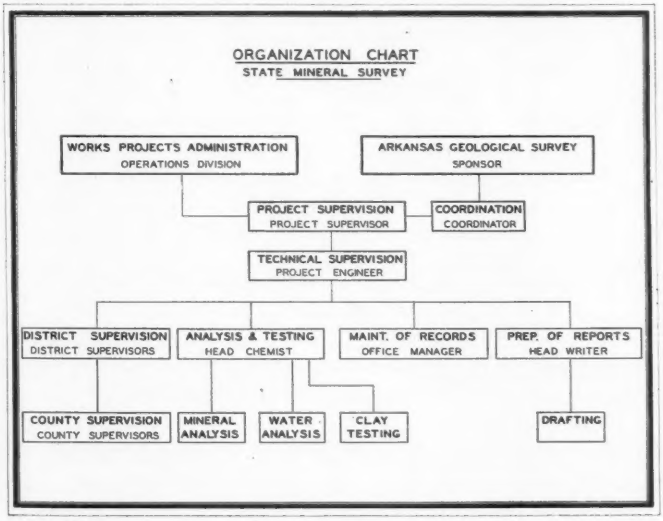


FIG. 1. Organization Chart.

survey have been divided into six districts, each with a non-relief district supervisor. (Fig. 2.)

Counties have separate organizations composed of a supervisor and his assistants. The assistants are taken from the relief rolls

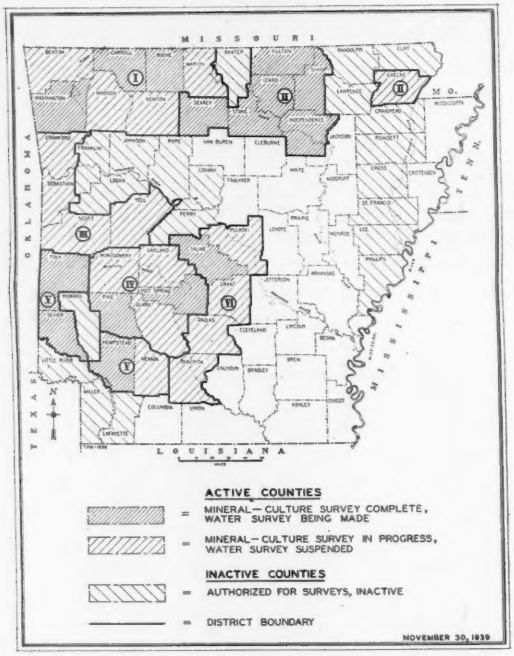


FIG. 2. Map Showing Area Surveyed.

of the county in which they work and are classed as party chiefs, notemen, typists, draftsmen, laborers, and truck drivers.

Before the field work was begun, a school of instruction, lasting two weeks, was held in Little Rock to train the district and county supervisors in their administrative and technical duties. Most of the supervisors selected had previous experience in engineering, geology, or mining.

The range of pay for supervision is as follows:

	Per Month
District supervisor	$125–$150
County supervisor	$100–$125
County chiefs-of-party	$55.90–$75.40
Administrative, special investigation and special technical workers	$74.10–$250

The pay for relief workers is from $31.20 to $75.40 for a maximum of 130 hours per month, the rate depending on the classification of the worker and the county in which he works.

WORK PROCEDURES.

Administration.

The central administrative office is located in Little Rock, Arkansas, and contains the office of the Project Supervisor, the Coordinator, and the Records and Reports Sections.

Field Procedure.

Crew Procedure.—The field crews usually work in pairs, two workers covering each square mile locating section corners, roads, buildings, wells, and springs on a mimeographed four-section plat. Two other workers, using similar plats, cover the same area locating rock outcrops and mineral localities and taking samples for identification or analysis.

Field Manual.—The details regulating the field work have been set forth in "A Manual of Technical Instruction," which was prepared by the Project Engineer and is issued to each field supervisor.

Field Sheets.—Two types of areal maps are prepared by the field workers. These are culture sheets and mineral sheets. Both are mimeographed four-section plats on a scale of two inches to the mile.

Culture sheets show the location of houses, wells, streams, and roads.

Mineral sheets show the locations of rock outcrops and the points at which valuable minerals occur and are sampled. Addi-

tional sheets are added which carry descriptions of each specimen and, when possible, an estimate of the quantity available.

Cross Sections.—Cross sections are made, usually one per land section, where the strata are sufficiently exposed so that vertical measurements of each bed may be made. Trenching is done wherever necessary to expose the beds for examination and measurement.

Mineral Sampling.—Specimens are taken of each deposit that appears to have economic value and include, for example, specimens of metallic minerals or such nonmetallics as gypsum, limestone, bauxite, clay, and some shales. All specimens are labeled to correspond with the locations shown on the mineral sheets.

Clay Sampling.—Clay samples are obtained by auger borings. Samples are taken every 1½ to 2 feet from each hole bored. Areas in which clay deposits of superior quality are found are bored sufficiently to determine the thickness and extent of each deposit.

Water Well Sampling.—Water wells are measured to determine both the depth and the water level with reference to a nearby fixed object. Yield is estimated from information obtained locally. Partial water analyses for chlorides, iron, carbon dioxide, and hardness are made in the county offices and from these data the state water chemist selects wells from which samples for complete quantitative analyses in the state laboratory are obtained. Usually water samples from four wells per township are completely analyzed.

Springs.—Springs are located on mineral sheets. Flow tests are made with a V-type weir. Partial and complete analyses are handled as are well water samples.

Surface Waters.—Samples of surface waters obtained from streams is systematically collected. Partial and complete analyses are handled as are well water samples.

County Office Procedure.

Aside from administration in connection with procuring field data, the following are the most important functions of the county supervisors:

Preparation of Tracings.—The four land section plats, both cultural and mineral, with supporting cross sections and other data, are retained in the field office until the township of 36 sections is complete. Two township tracings are then prepared in the County Office, on a scale of two inches to the mile, one showing culture and one minerals. Original field sheets and tracings are then submitted to the State Office where they are recorded and filed.

Preparation of Mineral Reports.—A written description is prepared by the county supervisor of each township indicating survey findings and specifying areas or localities in which certain minerals are believed to be especially important. This statement accompanies the township mineral sheets sent to the State Office and is used for the selection of areas that may require special investigations.

Samples.—All samples collected are labeled to show location and are grouped in containers by townships. When transportation becomes available, the samples, accompanied by a letter of transmittal, are sent to the laboratory.

Testing Procedure.

Organization.—The laboratory consists of three sections: the chemical laboratory, the ceramic laboratory, and the sample room, all located in Little Rock.

Chemical Laboratory.—Qualitative analyses are made of selected mineral specimens. Quantitative tests are made when necessary. Quantitative water analyses of selected samples are made in the state laboratory.

Ceramic Laboratory.—Small clay samples from the field are examined by the ceramic engineer and, if judged to be of good quality, a 100-pound sample is obtained from the deposit. Seventy-two large and thirty small test bars are then prepared for ten groups of tests to correspond with ten firing temperatures. A large kiln can be raised to 2500° F. and a small fusing furnace to 3000° F. Clays for special uses other than the manufacture of burnt clay products are sent either to the U. S. Bureau of Mines

clay laboratories at Tuscaloosa, Alabama, or at Norris, Tennessee, which are cooperating.

Sample Room.—The samples collected in the field are delivered to the sample room where they are classified. Those found to be of possible economic interest are retained and the point of collection indicated on township sheets. Usually about 8 per cent are retained. The remainder are described for reference and discarded, thereby reducing the bulk of samples on hand for storage.

Maintenance of Records.

The records section, located in downtown Little Rock, segregates and files all field and laboratory data in a manner appropriate for the use of the reports section, and for a permanent basic data file. It also handles all correspondence relating to the project.

Preparation of Reports.

The reports section, located with the records section, compiles and tabulates information bearing on the mineral resources of each county for the purpose of preparing county reports of the Survey findings. Studies are also made of all available data to determine the areas requiring further investigation.

A published report for each county or groups of counties surveyed and one for each separate testing program is the final end product of the project.

CONCLUSION.

After 23 months of trial and error in conducting the project, it can be said that work of the type described has proved to be of definite value. The major problem is to utilize the relief personnel in a manner whereby the results obtained are worth having. Apparently this problem can be met only by fitting the job to the worker, and not the worker to the job. Numerous minor problems, administrative and otherwise, arise in conducting a project of this size that can be solved only by the ingenuity and energy of the supervisory and technical staff.

Competent field, laboratory, and office supervision is of basic importance. Simple and clear-cut instruction for field and office procedure, shorn of all technical language, is vital to successful operation. The burden of obtaining the maximum values from the work rests squarely on the shoulders of the Project Supervisor and his supervisory staff. At present the tendency is to place less emphasis on the more general type of field surveying and more emphasis on limited and special field investigations which require drilling, boring or other types of sampling.

LITTLE ROCK, ARK.,
Jan. 25, 1940.

DISCUSSION AND COMMUNICATIONS

NATURE OF THE ORE-FORMING FLUID: A DISCUSSION.[1]

Professor Graton in his recent article has done an impressive job of marshalling and interpreting evidence concerning the nature of the ore-forming fluid, including its "source, composition and state of the mobile agent of transfer, the mechanism and the timing of separation of the metals and accompanying substances from the main body of magmatic material, the motive power for the task of transportation involved, and the conditions and causes of mineral deposition and attendant wall rock alteration accomplished by the moving fluid." The paper is worth while not only because of the author's broad background of experience with ore deposits but also because of the thoroughness with which he has gone over the ideas relative to the nature of the ore-forming fluid to be found in the literature. The following remarks are intended to supplement and clarify some of Graton's discussion, especially where it reinterprets the views that we have published both separately and together.

State of Solutions.—There is general agreement that the source of ore-forming solutions is a crystallizing magma, but the state in which, and the mechanism by which, these leave the magma are points on which agreement is lacking.

The condition of the magma in the later stages of differentiation is not known; we can only reason from geological observations interpreted in terms of the physical chemistry of solutions. It probably is generally believed that in the later stages the magmatic solution is largely of pegmatitic composition, with the accumulated accessory constituents, volatile and non-volatile,

[1] Graton, L. C.: Econ. Geol., 35: 197–358, 1940. Supp. to no. 2.

which have remained after the crystallization of the greater part of the original magma. These will consist of the oxides of rarer alkali metals; of halogens, boric oxide, phosphoric acid, carbon dioxide, sulphur; and of water. The amounts and relative proportion of these constituents will depend on the composition of the original magma and its subsequent history, and consequently each individual instance will show differences from the picture as a whole.

The further history of this assumed magmatic solution is what interests us primarily. In working it out investigators are handicapped by the confusion of geological observation, and by our lack of positive knowledge, especially of the water content that must be assumed at the various stages of differentiation. It is our opinion, however, that this primary magmatic solution is at no time in the supercritical state.

This term requires definition and to define it we must again discuss the occurrence of critical end-points. Inasmuch as we have considered this subject in some detail in a previous paper,[2] a brief summary should be sufficient.

In a binary system in which the solubility or fusion curve is continuous from the eutectic to the melting point of the higher-melting component, the critical or plait-point curve joining the critical points of the two components lies above the melting-point curve. By the melting-point curve is meant the curve giving the composition of the liquid phase coexisting with vapor and solid; associated with it is a curve giving the composition of the coexisting vapor. In the general case it must be assumed that this vapor phase contains both components, that is, that it also is a solution.

In a system of this type, critical phenomena are not shown by saturated solutions. A mixture of any given composition must be heated above the temperature of complete solution, and to an unknown correspondingly high pressure, before it can show critical phenomena, that is, before it can reach a condition in which liquid and coexisting vapor become identical in composition

[2] Morey, G. W., and Ingerson, Earl: The pneumatolytic and hydrothermal alteration and synthesis of silicates. ECON. GEOL., 32: 607–761, 1937.

and properties. An example of this case is the binary system H_2O—$K_2Si_2O_5$.

In the second case, the fusion curve is cut by the critical curve, and since the critical temperature of the second component is well above its melting point there must be not one, but two intersections, giving rise to the first and second critical end-points. In the region below the first critical end-point and above the second critical end-point there is coexistence of vapor, liquid and solid; in the region between the critical end-points only two phases are possible, solid and gas. Reference to Fig. 2 in the paper by Morey and Ingerson[3] shows that at the critical end-points, vapor and liquid phases become of identical composition; the gaseous or vaporous phase is itself a solution. Because it is above its critical temperature it is customary to consider it a gas rather than a vapor; and, because of the lack of outstanding distinction between liquid and gas, materials in this supercritical state are often referred to as "fluid" phases.

Morey[4] has been quoted many times as authority that "magmatic solutions" never attain the supercritical state, that is, that they never are in a condition above the critical point, not of water but of the complex magmatic solution, which is affected by every constituent. Graton, for example, says (p. 347):

> Therefore, it appears that Morey was entirely sound in his assertion that critical phenomena are improbable in magmas *or magmatic derivatives* . . . (italics are ours).

Now it is to be observed that there are two distinct ideas conveyed in this quotation. One is that magmas or magmatic solutions are never in the supercritical condition. We believe this to be true. To that has been added the phrase in italics "or magmatic derivatives." We are not entirely clear as to just what is meant.

The continuing process of fractional crystallization will give rise to mother liquors, magmatic solutions, continuously enriched

[3] *Idem.*

[4] Morey, G. W.: Relation of crystallization to the water content and vapor pressure of water in a cooling magma. Jour. Geol., 32: 291–295, 1924.

in water. These may be the "magmatic derivatives" referred to by Graton; if so, we are in complete accord.

We interpret it, however, as meaning a vapor phase coexisting with the orthomagmatic solution. The possibility of the existence of such a vapor phase repeatedly comes into Professor Graton's discussion, and we consider it desirable to make clear our views.

Formation of a vapor phase in mass within or adjacent to the liquid phase will depend solely on the relative pressures. The vapor pressure of the magmatic solution has a certain value; the solution is under a given external pressure. If the vapor pressure is greater than the external pressure a vapor phase will form; if less than the external pressure a vapor phase cannot form. As Graton says, to speak of this potential vapor phase as the "gas content" of the magma is lax terminology, which inevitably leads to confusion. Moreover, "boiling" would require a surface of discontinuity with opportunity for the vapor to escape. The formation of vapor is in general not probable.

Another mechanism is, however, not improbable. The magma is not enclosed in an impervious envelope. The overlying and surrounding materials are porous, and a vapor phase may pass into pores which are not traversed by the more viscous liquid phase. This is not a boiling, but it is a possible manner of separation of a "magmatic derivative." It is this possibility that was assumed by Ingerson.[5] This derived phase may percolate along cracks and fissures, and frequently is manifested around intrusives by a more or less uniform metamorphic aureole that is independent of fractures.

The vapor in equilibrium with a complex solution is of composition different from the liquid, and in the type of solution we are considering the differences will be great. If the vapor condenses to a liquid at a distance from the magma, that liquid, a solution of magmatic origin, will be different from the parent orthomagmatic solution. In particular, it is not impossible that a derived solution should exhibit critical phenomena, or should

[5] Ingerson, Earl: Relation of critical and supercritical phenomena of solutions to geologic processes. ECON. GEOL., 29: 454–470, 1934.

be obtainable in the supercritical condition. It is a system different in composition from the orthomagmatic solution.

Failure to keep in mind the distinction between these two types of magmatic derivatives caused Graton to remark that Morey and Ingerson have "expressed quite opposite views on the importance of critical phenomena in magmatic fluids," and to leave the impression that we tried, and failed, to patch up our differences in our joint paper on the subject of pneumatolytic and hydrothermal activity.[6] However, in previous papers Morey was discussing orthomagmatic solutions and Ingerson was discussing the aqueous solutions derived therefrom by the process mentioned above, and there was and is not the slightest disagreement. Ingerson has never contended that orthomagmatic solutions can ever go into the supercritical state, and Morey has never said that the vapor phase in equilibrium with such solutions is probably not above its critical temperature, that is, the critical temperature of a mass of the composition of the vapor.

Another misinterpretation arising from this same failure to distinguish between orthomagmatic solutions and their derivatives is found on p. 254: ". . . what he [Morey] plainly intended to imply was that such water of hot springs as is of magmatic origin comes, all the way from the magma, as liquid." Morey said what he meant in the passage quoted by Graton; that the *magma* remains liquid until *it* reaches the hydrothermal or hot-spring stage, but he neither said nor implied anything about the earlier emanations coming all the way to the surface as liquid.

Mechanism of Separation.—The formation of this vapor phase, and of the liquid solution derived from it where the temperature is lowered sufficiently, must be a perfectly continuous process. However, Graton, in spite of the important effects of the early-formed vapors (for which there is ample field evidence in metamorphic aureoles around intrusions), derives his ore-forming fluid by a sudden splitting of a residual magma into two immiscible liquid layers. Bowen[7] has shown that there is field

[6] Morey and Ingerson: *op. cit.*

[7] Bowen, N. L.: Evidence of liquid immiscibility in a silicate magma. Jour. Geol., 34: 71–73, 1926.

evidence against this idea, yet Graton makes the assumption that such a split can and does take place.

This assumption is not supported by any laboratory experience known to us. In the first place, if the solutions have the composition assumed by Graton, *i.e.*, a silicate-rich phase with 90 per cent silicate and 10 per cent water, and a water-rich phase with 5 to 10 per cent mineral solutes (p. 329), at a temperature where the silicate-rich fraction is liquid, the water-rich liquid would be above its critical temperature. A 10 per cent solution would have its critical temperature raised not more than 30° (Chitarow and Iwanow[8] found a 15 per cent solution of Na_2SiO_3 raised the critical temperature of water only 28°).

It appears to us inconceivable that a magmatic derivative containing 90 per cent silicate (largely silica and the components of feldspar molecules, if of near-pegmatitic composition) could be liquid at a temperature of not much over 400° C. In order to be liquid at such temperatures the silicate layer would have to be composed largely of alkali silicates. This is contrary to field evidence, and even if the solution did have this composition the laboratory evidence is that it would be miscible with a liquid containing 90 per cent water.

The presence of borates, sulphides, fluorides, etc. has been called upon to rationalize the idea of immiscibility. This is mostly speculation; experimental data are almost non-existent and such as there are do not favor the idea of immiscibility but rather make it even less probable. It is true that considerable percentages of the above-mentioned compounds do produce liquid immiscibility in some anhydrous silicate systems. In the system B_2O_3—CaO—SiO_2, which contains the largest area of immiscibility of any such ternary system thus far investigated, 9 per cent of Na_2O completely clears up the immiscibility. There would thus probably be enough alkali oxides in the layers assumed by Graton to eliminate any liquid immiscibility. If not, 90 per cent water in one of the layers would almost certainly preclude the possibility.

[8] Chitarow, N. I., and Iwanow, L. A.: Kritische Temperatur des Wassers und des wässerigen Lösung des kieselsauren Natriums. Zentr. Min., 1936, pp. 45–54.

In our opinion the weight of probability is against the hypothesis of liquid immiscibility as a process of magmatic differentiation, and that weight is overwhelmingly against liquid immiscibility in those stages in which water becomes increasingly important. Moreover, such an hypothesis is uncalled for, because the ever-present vapor phase affords a simpler and more probable mode of transfer.

The concept of transfer through a vapor phase is supported by theory and by experimental evidence. The notion that solubility ceases at the critical point has long been known to be untrue, and that real transport can take place is indicated by evidence gradually accumulated during many years' experience with aqueous solutions above the critical point of water.

Graton (p. 247) mentions ordinary laboratory experience such as quantitative separation by evaporation to dryness as evidence against gaseous solution. Obviously, only negligible quantities of non-volatile compounds will go into solution at atmospheric pressure, but at 500° C. and 9000 atmospheres pressure (p. 209) quite a different story can be told. The density, the amount of water in unit volume, is a major factor in solubility in a vapor phase, and at 500° and 9000 bars Goranson's equation [9] gives for the volume of 1 gram of water 1.929 c.c. The properties of water under such conditions are hardly to be compared with those in high-pressure boilers, and the evidence cited on p. 261 is not pertinent.

Solubility does decrease near the critical temperature in some systems, but there is no experimental evidence that solubility approaches zero in any system in which there is no change of phase near the critical temperature and no retrograde solubility at lower temperatures. Moreover, solubility increases above the critical temperature both with increasing temperature and pressure,[10] so it is quite possible that gaseous water under near-magmatic con-

[9] Goranson, R. W.: Silicate-water systems: Phase equilibria in the $NaAlSi_3O_8$—H_2O and $KAlSi_3O_8$—H_2O systems at high temperatures and pressures. Am. Jour. Sci., 35–A: 71–79, 1938.

[10] Hannay, J. B., and Hogarth, J.: On the solubility of solids in gases. Proc. Roy. Soc. (London), 29: 324–326, 1879.

ditions can dissolve more non-volatile material than liquid water can at 250–300° C. The material other than the dominant water can either be carried along by the water as it moves away from the magma, or can migrate through the gas by diffusion. Graton (p. 287) suggests diffusion to explain the extreme penetrating power of the ore fluid. It can operate just as well through gaseous water above its critical temperature as through liquid solutions.

The experimental evidence that water above its critical temperature can carry considerable amounts of non-volatile material in solution is well known. Graton cites it but points out that the compounds used have all been soluble ones and states categorically that "*we are able to count on only truly infinitesimal transport of SiO_2 dissolved in gaseous H_2O.*" In the first place, we do not need to have solubility of pure SiO_2 in gaseous water to give transfer of silica and deposition as quartz. Quartz is the primary phase in silicate solutions containing considerable quantities of other materials that would aid its solubility (*e.g.,* in solutions containing 25 per cent Na_2O).

This gives an adequate method of transfer, but recent evidence shows that quartz can be transported and deposited as such in the absence of alkalis. Recently, a steam furnace in our own laboratory was rebuilt, and during the operation some very interesting observations were made. The furnace had been in operation for nine months, and 250 runs had been made during which the average temperature of the closing bomb was 450° C. and the pressure was 3000 pounds per square inch. The temperature of the hot spot of the inside furnace varied from about 600 to 1050° C. During each run, from 20 to 30 grams of water was used, depending upon how much water was pumped in during the run. Therefore, the total amount of water used was more than 5000 grams and probably less than 7500 grams. When the bomb and furnace were dismantled, approximately 50 grams of quartz had been deposited on the baffles and near the top of the bomb. The silica was derived from the refractory tubes in the bomb and could not have been carried except through the gaseous water.

The runs varied from 2 to 24 hours in length, probably not long enough for the gaseous water to become saturated with

silica, especially in the late runs when much of the available silica had already been carried out of the tubes. But if all the water had been saturated during each run and all the silica deposited in the furnace each time, a solubility of 2/3 to 1 per cent would be indicated at this slight pressure. Diffusion and thus re-use of the solvent may be urged; very well, the same thing can and no doubt does take place in nature. Certainly this indicates more than "an infinitesimal transport of SiO_2 disolved in gaseous H_2O."[11]

During one run a silica tube was placed inside the furnace as an aditional baffle, and at the end of the run the platinum foil surrounding the charge was completely covered with fine silica. The charge hung entirely free of the silica tube.

Additional evidence is provided by the progressive contamination of the thermocouple in the steam furnace by iron from the surrounding bomb. The thermocouple hangs free in the gaseous water, yet it takes up iron[12] rapidly enough to make frequent calibrations essential. Recently boiled distilled water free of halogens is used, and it is protected from CO_2. Therefore, the iron must move as Fe, Fe_2O_3, or $Fe(OH)_3$, each of which is not only non-volatile but also very insoluble under ordinary conditions.

Graton (p. 260) interprets the experiments of Greig, Merwin, and Shepherd[13] as showing very slight transport of silica. These experiments were performed in evacuated tubes with low vapor pressure of H_2O, and any transport under such conditions would indicate considerable transport under magmatic pressure. These authors themselves do not feel that their experiment disproves

[11] We have recently obtained quantitative data (unpublished) showing definitely that distilled water dissolves more (alkali-free) silica at 500° C. and 575 atm. than at any temperature below the critical temperature of water. (Data at lower temperatures taken from the literature. Morey and Ingerson, 1937, Fig. 11.) The solubility is of the same order of magnitude as indicated by the silica deposition in the steam furnace and is enough to effect transport through the vapor phase of extremely important amounts of silica; more, in fact, than could possibly be carried by liquid water at any temperature.

[12] Determination by E. G. Zies.

[13] Greig, J. W., Merwin, H. E., and Shepherd, E. S.: Notes on the volatile transport of silica. Am. Jour. Sci., 25: 61–73, 1933.

gaseous transport of silica. Shepherd,[14] for example, feels that it shows that a little bit of water can make a good deal of silica move around.

With respect to the mechanism of separation of the ore-forming fluid as a gas or vapor, Graton assumes that reduced pressure and "boiling" are necessary (p. 254). We have already discussed this matter, and have stated our belief that there must be some pores or channels through which the solutions move, and these will be filled from the start with a vapor phase. There may be no important, or even detectable, results until differentiation has proceeded some distance, but the important thing is that the evolution of a gaseous phase is continuous in time and does not require sudden relief of pressure and boiling of the magma to initiate it. The character and quantity of the gas phase change as differentiation progresses, but the escape of material into it and through it is a normal and continuous process that involves less of a "guess" (p. 254) than does splitting of the magma into two immiscible liquid layers.

Motive Power.—Graton seeks to show that gas cannot provide motive power for driving solutions upward because in channelways the size of veins the water would run back and not be driven ahead of the gas. However, it is extremely unlikely that open spaces of such size exist in the pressure-temperature range where the solutions are gases, and nearer the surface the liquid is pushed on by liquid below it, which in turn is pushed by gas in the smaller channelways below.

Graton says (p. 349) that, "If the ore fluid leaves the magma as hot acid gas, most of it is likely to reach the surface as hot acid gas." That depends on the nature and temperature of the country rock. There is no reason why the emanations should not condense on cooling and so produce a liquid envelope around the gaseous envelope, and such a sequence appears more probable to us.

Deposition: (*a*) *State of Solution.*—There are no definite criteria for telling whether a deposit was formed from gaseous or liquid solution. When the pressure is above the critical pres-

[14] Private communication.

sure, solution, transport, and deposition are continuous; there is no sharp break at the critical temperature. For most ore deposits, therefore, field criteria can pobably not be found. There are three general cases:

(1) If the temperature is above the critical temperature, deposition is from the gas phase, no matter how high the pressure. This is a matter of definition.

(2) If the temperature is below the critical, the depositing solutions for most ore deposits would be liquid because the pressure is probably greater as a rule than the critical pressure of moderately dilute solutions.

(3) If temperature and pressure are both below the critical, the solutions may be either liquid or vapor, depending on the relation between temperature and pressure. This is the case in which intrinsically volatile compounds play an important part and may be largely confined to volcanic and other near-surface phenomena.

Cases (1) and (2) could be distinguished for a given deposit only if we knew the temperature and composition of the depositing solution. Even then in order to be sure that a given solution was liquid we should have to know that the pressure exceeded a certain value.

Obviously, it is impossible to know these factors definitely, and we may never be able to evaluate them. Yet Graton emphasizes the fact that Ross has based his ideas of ore-forming *liquids* on sound *geological* observation. But far from suggesting criteria as to whether the solutions were gaseous or liquid (cases 1 and 2), Ross has overlooked true gaseous solution and aims criteria at proving that *volatile compounds* are ordinarily not involved in the formation of ores; in other words, essentially the distinction between cases (1) and (2) and case (3).

For example, Ross (quoted by Graton, p. 305) cites the fact that at Ducktown the materials depositing the carbonates possessed exactly the order of solubility of these carbonates in the liquid phase of an aqueous solution, and the exact reverse of their transportability (volatility) in a chlorine-bearing gas phase, as evidence for liquid solution. However, the order of solubility

in a compressed gaseous water-rich phase probably would be the same as in a liquid aqueous solution, so this is no evidence at all against gaseous solution; it is evidence only against the action of one group of volatile compounds acting under imperfectly defined conditions.

The other geologic criteria likewise fail to invalidate the idea of gaseous solutions, applying equally well to such highly compressed solutions that must exist at depth as to liquid aqueous solutions.

(*b*) *Alkalinity.*—Graton favors a solution that is initially and continuously alkaline but admits that in some instances the evidence favors acidic solutions. The alkalinity of the solution must depend upon the composition of the original magma and the stage of differentiation at which a given portion of solution comes off. In general, the early fractions are likely to be more acidic; the later ones, especially the residual primary fluid when it has reached the hydrothermal stage, are more likely to be alkaline. Each deposit is a separate problem, and the paragenetic relationships in each case should enable one to decide whether the solutions were acidic, alkaline, or changing in alkalinity.

Incidentally, we are in sympathy with Graton's remarks concerning the use of the terms acid and alkaline. As at present defined, "Any electrolyte which gives hydrogen-ion (H^+) as one of the direct products of its ionization is called an acid," the terms become useless in talking about most of the solutions with which the geologist is concerned. Nevertheless, the terms as used in the older and broader sense, although more difficult to define, convey a meaning which cannot otherwise be conveyed without circumlocution and their retention causes no confusion.

The "relative strength of acids" is determined by their degree of ionization, and hydrolysis is determined by the degrees of ionization of salt and water. But the ionization constant of water increases with temperature until a maximum is reached a little above 200°, after which it decreases. Extrapolation to temperatures above the critical temperature of water is without justification. The statement has been made[15] that at high tem-

[15] Arrhenius, S.: Kosmische Physik, S. Hirzel, Leipzig, 1903, p. 312.

peratures water becomes a stronger acid than silicic acid. The evidence is so scanty that the statement becomes an unsupported assertion.

SUMMARY.

(1) *State.*—(*a*) Orthomagmatic solutions (*i.e.*, the magma itself) are probably never above their critical temperature but remain liquid until (and if) they reach the hydrothermal stage.

(*b*) Magmatic emanations in eqilibrium with the magma are almost certainly gaseous near the magma because they are above their critical temperature, but they may condense to liquid at other places where the temperature is low enough.

We have endeavored to bring out the possibility of the existence of a gaseous phase derived from the magma, and the transport of material by means of and through this vapor phase. Such a vapor phase cannot form in volume in or above the magma when the reigning pressure is above the vapor pressure of the magma; but such a vapor phase may emanate from the magma through pores and cracks in the surrounding rock. As to the relative importance of gases and liquids in the formation of actual ore-bodies, there is a paucity of convincing evidence either from field observations or from laboratory studies. It is considered probable that most ore-forming fluids were generated late in the cycle. Therefore, most of them may be the residual orthomagmatic solutions that were never gaseous. Such solutions may form most ore deposits, but it should be recognized that gaseous solutions must be present during the magmatic cycle and that they can effect considerable transport of non-volatile material. That they have done so can neither be proved nor disproved; until much more evidence has been obtained both from the field and from the laboratory it is not possible to evaluate the relative importance of these two processes in ore deposition.

(2) *Mechanism of Separation.*—If ore-forming fluid is separated as a different phase from the magma, rather than being the magma in its final stage, our belief is that separation as a gaseous phase by the mechanism detailed above is much more nearly in accord with field and laboratory evidence than is separation as an immiscible liquid.

(3) *Timing.*—The separation of a different phase is thought of as a continuous process, maintaining equilibrium with the magma from the start, rather than being generated spontaneously late in the cycle. In the early stages the gaseous phase may be commonly unimportant, but in a complete discussion one should realize that it is always present. In some cases it has left a clear record of its activity in fairly early stages. The later solutions, whether gaseous or liquid, are doubtless much more important as ore-formers.

(4) *Motive Power.*—Gas pressure is considered to provide at least a part of the propelling force. Collapse of the roof would tend to pump compressed gaseous as well as liquid solutions upward.

(5) *Deposition:* (*a*) *State.*—Three cases are mentioned, and the impossibility of telling from field evidence whether the depositing solutions were liquid or gaseous is pointed out. Evidence for or against the activity of volatile compounds can be found in textures and parageneses.

(*b*) *Alkalinity.*—The character of the solutions with respect to alkalinity or acidity is a problem that must be worked out for each individual deposit.

EARL INGERSON,
GEORGE W. MOREY.

GEOPHYSICAL LABORATORY,
CARNEGIE INSTITUTION OF WASHINGTON,
WASHINGTON, D. C.
July 10, 1940.

REVIEWS*

Contributions to a Knowledge of the Lead and Zinc Deposits of the Mississippi Valley Region. Geol. Soc. America. Special Papers No. 24. Edit. Edson S. Bastin. 15 Contributors. Pp. 156; Pls. 4; Figs. 27. 1940.

The purpose of this volume is to give a "critical summary of certain geological factors lying at the foundation of any adequate understanding of the genesis of the ores" of this important metal producing region.

The principal geological factors considered in the paper are: stratigraphy, structural features, igneous rocks, and paragenesis of the ores. Less space is devoted to other factors such as zoning, similar districts elsewhere, composition and temperature of the mineralizing solutions, the source of metals and cause of precipitation. Since the ore deposits are all in sedimentary rocks much attention is paid to the stratigraphy. In the Tri-State district the ore deposits are in Mississippian rocks, in northern Arkansas they are in the Ordovician and Mississippian, in southeastern Missouri principally in the Cambrian, and in the Wisconsin-Illinois district and in central Kentucky they are in Ordovician rocks.

It is thus apparent that the ores occupy quite different stratigraphic positions in the several districts, and it is concluded that the age of the ore-containing strata appears to have little significance with regard to origin of the ores.

In the Mississippi Valley the Paleozoic beds have been flexed into broad domes and basins but with deformation so slight that regional dips of more than one degree are rare. In the Tri-State district the Horse Creek and Joplin anticlines were probably formed near the close of the Paleozoic, and the Seneca fault or syncline and the Miami syncline are probably Mesozoic. The discussion of the structural features to which the ore deposits are related in the Tri-State district follows the previous descriptions by Fowler, and emphasis is placed on the influence of deformation in preparing permeable loci for ore deposition. In northern Arkansas some ore deposits are in faults, some with minor structural features related to the faults, and some without associated faults. In this district

* Books noted under *Reviews* and *Books Received* may be ordered through the Economic Geology Bookshop, W. S. Bayley, Urbana, Ill., but orders for official reports and single copies of Journals should be sent directly to their publishers.

as well as in the Tri-State certain of the rocks, due to their physical properties, tended to fracture so as to be favorable for ore introduction. The structural features with which the ore deposits are related in the southeastern Missouri lead district and in the central Kentucky vein district receive scant discussion. In the latter district the veins are along or close to well defined zones of faulting. Mineralized faults are also moderately common in the Wisconsin-Illinois-Iowa lead-zinc district, but most of the ore occurs in partings parallel to the bedding planes near but not in the bottom of the basins, or in associated shatter zones, in the joints or crevices and disseminated in shaly beds.

The age of the igneous rocks in the Mississippi Valley that are younger than the pre-Cambrian is indefinitely known. Some intrusive rocks that are probably but not certainly pre-Cambrian include a small exposure of granite pegmatite at Decaturville, some granite outcrops at Spavinaw, and granite encountered at a depth of 1246 feet in a well near Picher—all in Oklahoma. The intrusives definitely younger than pre-Cambrian are present in widely separated localities in the central Mississippi Valley, but none within the major lead-zinc producing regions. Most of the intrusives cut rocks of Paleozoic age but some in Arkansas cut early Cretaceous rocks of the Coastal Plain. Differences of opinion exist as to whether more than one epoch of intrusion is represented. The closest areal association of igneous intrusions with the metalliferous deposits is in southeastern Missouri where 71 occurrences of diatremes and basic dikes appear some miles to the southeast of the lead district. The igneous material is mostly peridotitic but in places feldspar is present in the rock.

In fact peridotites are the most prevalent and characteristic igneous rocks in the whole central Mississippi Valley. Alkalic and acid to intermediate types of igneous rocks are found however. Many of the intrusions appear to be hypobyssal.

The five primary minerals present in all seven ore-bearing districts are pyrite, chalcopyrite, galena, sphalerite and calcite. Quartz and marcasite are present in six. It is concluded that a prevailing sequence of deposition is present in each district; that repetition of any considerable part of the sequence is rare; that most of the districts show little similarity in the order of deposition—even in the chief minerals. For example, the order in the Tri-State district is commonly galena, chalcopyrite and marcasite, but in southeastern Missouri the reverse order prevails. In all the districts the solutions at the time of sulphide deposition seem to have been poor in silica. Colloform structures or textures are confined mainly to the Wisconsin-Illinois district.

A critical summary of the origin of the deposits is given by Bastin and Behre. In addition to the evidence that has been mentioned on these pages much other information is summarized under the headings meteoric

hypotheses and the magmatic hypothesis. The writers find more evidence favoring the latter view. The reviewer agrees in a general way with this weight of evidence and perhaps because he agrees considers that this symposium was well conceived, and the final summaries weighted with good judgment. New workers have added much significant data to that known twenty years ago and much of it is here summarized but much yet remains to be learned. For example, within the Tri-State district where was the locus or loci of ingress of the mineralizing solutions into the ore-bearing horizons? Did the solutions ascend from depth along the fractures to which the ore bodies are related, or did they come up elsewhere and move laterally through the fractured horizons? If the solutions moved along the fractured horizons, what point of the compass did they move toward to reach faults passing upward through overlying shale to the earth's surface, or were the solutions dissipated in the fractured rocks beyond or to the lee of the ore bodies? The direction of movement of the solutions that formed the ores can be determined[1] and systematic areal examination of the ores from this standpoint should be undertaken.

R. C. Moore states "that paleogeographic studies make not unreasonable the conclusion that Pennsylvanian sediments formerly covered all of the Mississippi Valley ore bearing districts." If this is true may not the Tri-State ores have been deposited under a fairly deep cover, possibly at a depth of one to several thousand feet. S. Weidman[2] has called the reviewer's attention to a diamond drill core from the Oklahoma City oil field, consisting of "dark-colored dolomite, containing sphalerite associated with white dolomite like that occurring with the zinc ore in the Tri-State district." This was taken at a depth of 6319 feet from the I.T.I.O. Company No. 1, H. V. Foster well Sec. 24, T 11 N, R 3 W.

The deposits in the Mississippi Valley as well as those of this type elsewhere in North America, including those of Friedensville, Pa., Austinville, Va., eastern Tennessee and southern Ontario in the main show little or no colloform textures or structures. Exceptions in North America are those in the Wisconsin-Illinois-Iowa district and those near Great Slave Lake, N.W.T. In contrast, a number of the deposits in Europe, including those in upper Silesia; Moresnet, Belgium; Iserlohn, Westphalia; and Weisloch, Baden; consist in small or large part of ores with pronounced radial growths, colloform textures of the zinc and iron sulphides, and fine-grained zinc sulphide. Repeated banding of the minerals is present in some. Were these formed at lesser depths and like epithermal deposits revealed by much less erosion than those in North America?

[1] Science. New Series, vol. 88, July 29, 1938, p. 109.

[2] Letter accompanied by drill core.

R. E. Stoiber has found that a different suite of minor elements characterize the zinc sulphide from these European deposits as compared with those in the United States.

If reliable data could be assembled on the paleogeography and the time of ore deposition of these districts, it might be possible to decide whether depth or a different composition or concentration of the ore depositing solutions was the chief factor responsible for these differences. Possibly variation in both factors is essential.

Erosion has uncovered several districts of major importance in the Mississippi Valley. Do other undiscovered ones exist at mineable depths with an upper or more "far traveling" halo of alteration effects or minerals intersected by the present erosion surface? For example, carbonate containing a special assemblage of minor elements might characterize such an upper or outer zone. Work that has been done on mineralizations of a variety of types in the Spectrographic Laboratory of the Geology Department at the Massachusetts Institute of Technology suggests that if any such products exist in the known districts they would be worthy of careful investigation from this viewpoint. Whether such an outer faint zone is present and connected areally and in time with the valuable mineralization the writer does not know.

Among other features of interest that remain to be explained are: the relatively high content of lead in the Miami syncline as compared to the ore in the rest of the Miami-Picher district;[3] the relations of the iron-rich mineralizations (specularite or pyrite or iron-bearing carbonate, the latter two in places oxidized) in the Ozark region, Friedensville, Pa., Austinville, Va., Embreeville, Tenn., and also with some of the European deposits. Are the lead-zinc and iron mineralizations zonally separated parts or are they successive stages of the same mineralization? Some relationship of the barite deposits near Sweetwater, Tenn., and the important ones in Missouri with the somewhat removed lead-zinc deposits of the same regions may be suspected but remains to be proven. Further progress may be expected in the knowledge and understanding of these deposits and similar ones elsewhere when the modern concepts of minerals and the solid state are applied to areal mineralogical studies guided by the structural features to which the ores are related. Certain elements in minor amounts are known to be present in solid solution in minerals from these districts. For example, gallium, germanium, nickel and cobalt are present in spectrographically measurable amounts in solid solution in sphalerite, and magnesium, aluminum, silicon, strontium and vanadium as well as other elements are present in galena from the Tri-

[3] Weidman, S.: Miami-Picher zinc-lead district. Univ. Oklahoma Press, 1932, pp. 75–76.

State district. Detailed spectrographic studies of sulphides from other mining camps by P. E. Auger have shown that the relative quantities of such minor elements in (minerals) solid solution vary systematically with respect to certain important geological features. These minor elements in solid solution constitute measuring sticks of geological change (temperature or concentration) with much finer subdivisions than have hitherto been available.

The volume under review emphasizes the gains of the last two decades and has separated much of the wheat from the chaff. Further detailed field work coupled with studies of the ores by modern methods should make even larger advances in the next two decades.

W. H. NEWHOUSE.

GEOLOGY DEPARTMENT,
MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
CAMBRIDGE, MASS.,
June 9, 1940.

Texas Oil and Gas Since 1543. By C. A. WARNER. Pp. 487. Gulf Publishing Co., Houston, Texas, 1940. Price, $5.00.

This volume by a petroleum geologist of the Houston Oil Co. deals with the rise and present status of the petroleum industry of Texas, an industry much greater than Texas agriculture and which employs over a million people. Of its 11 chapters, the first deals with the historical development (77 pp.), the second with the economic importance and growth of the industry, the third with the stratigraphy and structure and the next six with the different sections of the state. The concluding chapters deal with historical documents and statistics (100 pp.), and a bibliography.

BOOKS RECEIVED.

DAVID GALLAGHER.

Geology of the Country around Bulawayo. F. L. AMM. Pp. 307; pls. 26; geol. map in color, 19″ × 29″, scale 1: 100,000. Southern Rhodesia Geol. Surv., Bull. 35. Salibsury, 1940. Price 10s. 3½d. *A detailed and comprehensive account of the geology together with descriptions of 514 gold mines.*

Mining Industry and Statistics of the Province of Quebec for the Year 1938. Pp. 130; pls. 3. Quebec Bureau of Mines. Quebec, 1939.

Phenomena in the Ignition of Firedamp by Explosives. S. L. GERHARD AND W. J. HUFF. Pp. 17; figs. 12. U. S. Bureau of Mines, Tech. Paper 603. Washington, 1940. Price 10 cents. *Part one of this research, covering the particles from the detonation.*

Metal-Mine Accidents in the United States: 1937. W. W. ADAMS AND M. E. KOLHOS. Pp. 54; tables 37. U. S. Bureau of Mines, Bull. 428. Washington, 1940. Price 10 cents.

Quarry Accidents in the United States: 1937. W. W. ADAMS AND V. E. WRENN. Pp. 73; figs. 3; tables 45. U. S. Bureau of Mines, Bull. 426. Washington, 1940. Price 15 cents.

Geology of the Gold Coast and Western Togoland. N. R. JUNNER. Pp. 40; pls. 9. Geol. map in color, 20″ × 30″, scale 1:1,000,000. Structure map 9″ × 14″. Gold Coast Geol. Surv., Bull. 11. 1940. Price 4/-. *A revised account of the geology based on the most recent data; map includes data obtained up to July 1938.*

O Ferro de Jequié, Estado da Baía. J. L. DE MELLO, JR. AND M. DA S. PINTO. Pp. 56; figs. 10. Serv. de Fom. da Prod. Min., Bol. 39. Rio de Janeiro, 1940.

Geology and Ore Deposits of the Atikokan Area, E. S. MOORE; **Iron Deposits of the Steeprock Lake Area,** M. W. BARTLEY; and **Geophysical Work at Steeprock Lake,** 1938–39, A. BRANT. Pp. 55; figs. 52; two geol. maps in color, 24″ × 24″, scale 1: 63,360, and 28″ × 18″, scale 1: 15,840. Ontario Dept. Mines, Annual Rpt. XLVIII, Pt. II, 1939. Toronto, 1940. *Promising area but only small gold deposits to date; hematite body under Lake but no commitments as to value.*

Geology and Gold Deposits of the Uchi-Slate Lakes Area, and Geology of the J–M Consolidated Mine. J. D. BATEMAN. Pp. 57; figs. 33; geol. map in color, 29″ × 27″, scale 1: 31,680. Ontario Dept. Mines, Annual Rpt. XLVIII, Pt. VIII, 1939. Toronto, 1940. *Detailed general geology, gold ores, descriptions of deposits and mines.*

Agua Subterrânea em Minas Gerais. O. BARBOSA. Pp. 40; figs. 6. Brazil Div. de Fom. da Prod. Min., Avulso 43. Rio de Janeiro, 1940.

História da Pesquisa de Petróleo no Brazil. E. P. DE OLIVEIRA. Pp. 208; 1 pl. Brazil Ministério da Agric. Rio de Janeiro, 1940. *This is the last work, posthumously published, of Euzebio Paulo de Oliveira, great leader among the geologists of Brazil. It contains a memorial preface by his successor, Glycon de Paiva, a portrait of de Oliveira, and a complete bibliography of his works embracing one hundred and forty-three titles.*

Petrologia das Jazidas de Apatita de Ipanema, São Paulo. V. LEINZ. Pp. 52; pls. 10; figs. 5. Brazil Div. de Fom. da Prod. Min., Bol. 40. Rio de Janeiro, 1940.

Relatório da Diretoria, 1938. A. I. DE OLIVEIRA AND O. BARBOSA. Pp. 180. Brazil Div. de Fom. da Prod. Min., Bol. 41. Rio de Janeiro, 1940. *Review of Brazilian mineral production.*

Contribution à l'Etude Géologique de Gisement cuprifère de Musoshi, Katanga meridional. A. JAMOTTE. Pp. 64; figs. 37. Assoc. des Ing. de la Fac. Polytech. de Mons, 5e fascicule, 1939, No. 74. *This paper received the Jules Cornet prize for the period 1931–36. The author rejects the sedimentary syngenetic hypothesis of origin, and concludes that the Roan series possessed peculiar primary sedimentary features that promoted the precipitation of copper, and that the metamorphism and mineralization were closely related and due to a granitic intrusion.*

SCIENTIFIC NOTES AND NEWS

C. W. WRIGHT, foreign mineral specialist for the U. S. Bureau of Mines, has left for Brazil after spending several weeks in Buenos Aires.

W. H. BROWN, mining geologist of the Empire Zinc Co., has been transferred to Hanover, New Mexico from Gilman, Colorado.

WILLIAM BENSON of the department of geology of Yale University is working up a report on the non-metallic mineral resources of Connecticut for the State Geology and Natural History Survey.

EDWARD WISSER has been making mine examinations in Sinaloa and Durango, Mexico, which were finished in July.

JOHN PAYNE, JR. has resigned as chief geologist and engineer for Surigao Consolidated Mining Co., Inc. and Mindanao Mother Lode Mines, Inc. in the Philippines because of the unsettled world conditions and possible trouble in the Orient.

W. L. RUSSELL, geologist of the Michigan Devonian Petroleum Co., has been transferred to Tulsa, Oklahoma from Macomb, Illinois.

E. W. SKEATS, professor of geology who has been at the University of Melbourne for 36 years, is retiring next February.

H. C. SYKES, consultant on mica, and IRWIN VOGELSANG, consultant on tin, have recently been appointed to the raw-material division of the National Defense Advisory Committee.

C. H. STEELE, senior geologist for Anaconda Copper Mining Co. in Butte, was awarded the professional degree of geological engineer by the Montana School of Mines.

N. B. KNOX, professor of geology and director of the Instituto de Geologia at Caracas, Venezuela, is spending the summer in the United States collecting material for a course in economic geology.

G. M. KIRWAN is now engineer geologist for Chlorine Products Corp. in Gustine, California. He was formerly in Peru with the Cerro de Pasco Copper Corp.

W. H. WILLIAMS has been appointed Secretary for Mines in Tasmania to succeed the late J. B. SCOTT.

PHILIP KRIEGER, professor of geology at Columbia University, was killed Sunday, August 18 in an automobile accident while driving to Gouverneur from North River, New York.

B. C. FREEMAN, instructor in Economic Geology, Ohio State University, died in the field in Northern Quebec, in August.

ADVERTISEMENTS

Patrons of this journal are requested to refer to ECONOMIC GEOLOGY when consulting advertisers.

A Complete Plant Under One Roof

PRINTING ~ BINDING ~ ELECTROTYPING

Printers of
Scientific and Technical Journals and Books
Theses and Dissertations
Works in Foreign Languages

Your Book, Journal or Thesis placed with us insures that the composition, proof-reading, electrotyping, presswork and binding follow through in consecutive order in one plant—established sixty-three years ago—and under the supervision of one management. : : :

LANCASTER PRESS, Inc.

Established 1877 LANCASTER, PA.
[*Printers of Economic Geology*]

Minerals and Rock Specimens

Large variety of MINERALS by weight for class work and for laboratory purposes. Freight paid on all shipments valued at $25 and over.

R. M. WILKE, Box 312 PALO ALTO, CALIF.

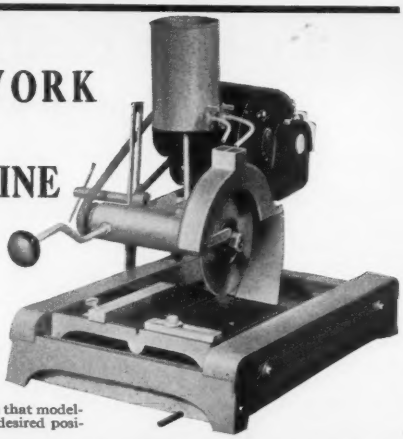
VOL. XII, NO. 2
of the
ANNOTATED BIBLIOGRAPHY OF ECONOMIC GEOLOGY
is nearly ready to mail
Price $5.00 a volume
Order from
ECONOMIC GEOLOGY PUBLISHING CO.
URBANA, ILL.

THIN - SECTIONS
AND
POLISHED SECTIONS

Prices reasonable

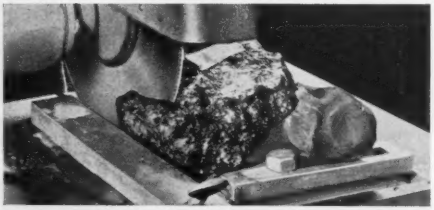
RUDOLPH VON HUENE
281 S. HUDSON AVE.
PASADENA, CALIF.

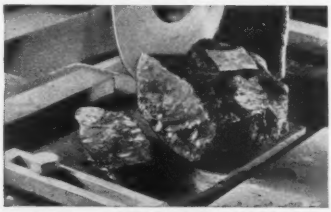
PREPARE YOUR PETROGRAPHIC WORK with the FELKER DI-MET MACHINE



The Felker Di-Met Machine, equipped with the Felker Di-Met diamond impregnated blade, makes it possible to obtain saw cuts from rock easily, quickly and accurately—and from any position. Write for Bulletin Pl-39. Musto-Keenan Co., Sales Division, 1801 South Soto St., Los Angeles.

BELOW: The Felker Di-Met Blade cuts with such ease that modeling clay is sufficient to hold the rock in any desired position. No clamps are necessary.





REVUE DE GEOLOGIE et des Sciences connexes
RASSEGNA DI GEOLOGIA e delle Scienze affini
REVIEW OF GEOLOGY and Connected Sciences
RUNDSCHAU FUR GEOLOGIE und verwandte Wissenschaften

Published monthly with the cooperation of the Fondation Universitaire de Belgique, under the auspices of the Société Géologique de Belgique, with the collaboration of many National Geological Surveys, Scientific Institutions and Geologists throughout the world.

Secrétariat général of the REVUE DE GEOLOGIE: Institut de Géologie, Université de Liége, LIÉGE Belgique).

The REVUE DE GEOLOGIE is par excellence the review of geological reviews; it is not a commercial undertaking, but its aim is to secure a cordial collaboration among geologists of all countries; it publishes summaries of their works and arranges exchanges of documents among its subscribers.

The subscription price of vol. XX (the current volume) is 36 belgas.

Address: M. G. TIBAUX, Treasurer of the REVUE DE GEOLOGIE, rue de l'Enclose, 11, Liége (Belgique).

Sample Copy Sent on Request.

SWAN ENGRAVING COMPANY

PHOTO ENGRAVERS COMMERCIAL ARTISTS

BRIDGEPORT, CONN. NEW HAVEN, CONN

POUGHKEEPSIE, N.Y.

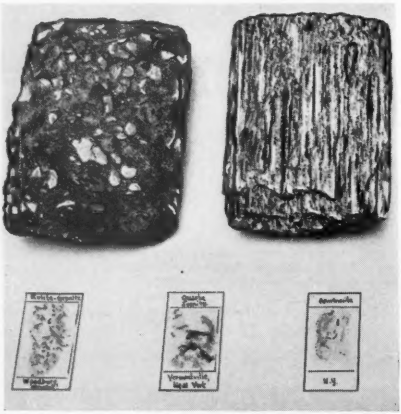
THE SOCIETY OF EXPLORATION GEOPHYSICISTS

•

A CUMULATIVE INDEX of Society publications from 1931 through 1939 has been prepared and is now available at Society Headquarters. Those who are interested in completing their geophysical libraries may obtain a copy by addressing

THE SOCIETY OF EXPLORATION GEOPHYSICISTS
P. O. BOX 777 AUSTIN, TEXAS

Join
the
RED CROSS
and
Help the Suffering



NEW
Ward's Collection of American Rocks

This new collection consists of 100 selected, typical hand specimens including 46 igneous, 32 sedimentary, 22 metamorphic rocks; a complete descriptive manual; and, when desired, 100 expertly prepared thin sections. The set is designed to cover a year's class work in petrology. We invite correspondence concerning this carefully worked out collection and will gladly supply additional information. The collection is prepared and priced in a variety of ways; one of the most suitable is our **WPR-1**, 100 rocks neatly trimmed to standard museum size, 3″ x 4″. Supplied with printed labels, Ward's Improved Specimen Trays and Descriptive Manual. **Per set . . . $60.00.**

WPRs-3, 100 thin sections of above rocks on 26 x 47 mm. Slides in wooden boxes. **Per set . . . $100.00.**

WARD'S NATURAL SCIENCE ESTABLISHMENT, INC.
EST. 1863
290 GOODMAN ST. NORTH • • ROCHESTER, N. Y
THE FRANK A. WARD FOUNDATION OF NATURAL SCIENCE OF THE UNIVERSITY OF ROCHESTER

GEOLOGISCHES ZENTRALBLATT

ABTEILUNG A: GEOLOGY

GEOLOGISCHES ZENTRALBLATT appears on the first and fifteenth of each month in parts containing 4–5 signatures. Nine parts constitute a volume. Fifty-six volumes (1901–1936) have been published.

ABTEILUNG B: PALEONTOLOGY

PALAEONTOLOGISCHES ZENTRALBLATT appears in a single part of 4–5 signatures each month. Eight parts constitute a volume.

The price per volume of the Geologischen Zentralblatt (Abt. A) is 48 Rm.

The price per volume of the Palaeontologisches Zentralblatt (Abt. B) is 48 Rm.; seven volumes have appeared.

Address: *Gebruder Borntraeger*, Berlin, W. 35., Germany

MAAS Determines Direction and Dip of Drill Holes

Drill Hole Compass

E. L. DERBY, Jr., Agent, Ishpeming, Michigan

14-7 CODE: McNeill's, 1908

LABORATORY FOR ROCK ANALYSES

Chemical analyses of rocks and rock minerals made with the accuracy required for research work in petrography: for students, geologists, and surveys. Moderate prices.

FRANK F. GROUT, in charge

GEOLOGY DEPARTMENT, UNIVERSITY OF MINNESOTA

MINNEAPOLIS, MINNESOTA

An A.A.P.G. Book (1939)

RECENT MARINE SEDIMENTS

A SYMPOSIUM OF 34 PAPERS BY 31 AUTHORS

EDITED BY

PARKER D. TRASK

U. S. GEOLOGICAL SURVEY, WASHINGTON, D. C.

PREPARED UNDER THE DIRECTION OF A SUBCOMMITTEE OF THE COMMITTEE ON SEDIMENTATION OF THE DIVISION OF GEOLOGY AND GEOGRAPHY OF THE NATIONAL RESEARCH COUNCIL, WASHINGTON, D. C.

This book is on the topic of Sedimentation and Environment of Deposition recently voted No. 1 in geological research of most importance to the progress of petroleum geology—in a poll of the 3,000 A.A.P.G. members and associates, conducted by the Research Committee. Throughout the book, the basic data—observational facts—are emphasized rather than speculative inferences.

- 736 pages; 139 figures
- Bibliographies of 1,000 titles; 72 pages of author, citation, and subject index
- Bound in blue cloth; gold stamped; paper jacket; 6 x 9 inches

PRICE: $5.00, POSTPAID

($4.00 TO A.A.P.G. MEMBERS AND ASSOCIATE MEMBERS, LIBRARIES, AND COLLEGES)

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

BOX 979, TULSA, OKLAHOMA, U.S.A.

NEW BOOK LIST

The books in the following list are all recent publications. Address ECONOMIC GEOLOGY, Urbana, Ill. Books not in this list (except the publications of official Surveys and those of the Geological Society of America) will be furnished at Publishers' prices. THE PRICES OF ENGLISH BOOKS ARE QUOTED WITHOUT DUTY. THE PRICES OF ALL FOREIGN BOOKS VARY WITH THE EXCHANGE.

Ore Deposits of Magmatic Origin. By P. NIGGLI. Trans. by H. C. BOYDELL 2.70
Field Geology. 3d Ed. By F. H. LAHEE 5.00
German-English Geological Terminology. By W. R. JONES and A. CISSARZ. Pp. xv + 250. Cloth. 3.25
A French-English Vocabulary in Geology and Physical Geography. By G. M. DAVIES. Pp. ix + 140. Cloth, 8vo 1.75
Treatise on Sedimentation. 2d Ed. Rewritten. By W. H. TWENHOFEL. Pp. xxvi + 914. Figs. 121. Cloth, 6 x 9 ..... 8.00
Metamorphism. By A. HARKER. Pp. ix + 260. Figs. 185. Cloth, 6 x 9 ..... 5.90
Mineral Deposits. 4th revised Ed. By W. LINDGREN 6.50
The Determination of the Feldspars in Thin Section. By K. CHUDOBA. Trans. by W. R. KENNEDY. Pp. 75. Figs. 50. Cloth, 8vo 1.75
Die Bodenschätze des Staates Minas Geraes, Brasilien. By B. v. FREYBERG. Pp. xvi + 453. Figs. 73. Pl. 12. Paper 20.50
Grundzüge der Geologie und Lagerstättenkunde Chiles. By J. BRUGGEN. Pp. viii + 362. Figs. 69. Pl. 4. Paper 13.25
The Strategy of Raw Materials. By B. EMENY. Pp. 202. Maps, etc., 29 ..... 3.00
Handbook for Prospectors. 3d Ed. By M. W. VON BERNEWITZ. Pp. 372. Illus. 105. Cloth, 5 x 7¼ 3.00
Prospecting and Operating Small Gold Placers. 2nd Ed. By W. F. BOERICKE. Pp. 144. Illus. 30. Cloth, 5 x 7½ 1.50
The Geology of Southwestern Ecuador. By G. SHEPPARD. Pp. xi + 275. Illus. 195. Cloth 6.25
Gold Deposits of the World. By W. H. EMMONS. Pp. 552. Illus. Cloth, 6 x 9 ..... 6.00
Elements of Optical Mineralogy. Pt. I. Principles and Methods. 5th Ed. By A. N. WINCHELL. Pp. 263. Illus. 305. Cloth. 6 x 9 ..... 3.50
Geological Nomenclature. Edited by L. RUTTEN. Pp. viii + 339 Illus. 58. Cloth, 8 x 11 ..... 6.75
The Cycle of Weathering. By B. B. POLYNOV. Trans. by A. MUIR. Pp. xii + 220. Cloth, 5½ x 8½ 2.75
Our Wandering Continents. By A. L. DU TOIT. Pp. 364. Illus. 48. Cloth, 8vo 4.75
Principles of Structural Geology. 2d Ed. By C. M. NEVIN. Pp. 348. Figs. 163. Cloth, 6 x 9 .... 3.50
Economic Geology. 7th Ed. By H. RIES. Pp. 720. Figs. 378. Cloth, 6 x 9 ..... 5.00
Earth Lore. By S. J. SHAND. Pp. viii + 144. Figs. 33. Cloth, 5¼ x 7½ 1.75
The Science of Petroleum. By 300 authorities. 4 Vols 85.00
Scientific Illustration. By J. L. RIDGWAY. Pp. 210. Illus. Cloth, 7 x 10 ..... 4.00
Introductory Economic Geology. 2d Ed. By W. A. TARR. Pp. 645. Illus. Cloth, 6 x 9 ..... 5.00
The Origin of Life. By A. I. OPARIN. Trans. by S. MORGULIS. Pp. 270. Cloth 2.75
Studies on the Periodicity of Earthquakes. By CHAS. DAVISON. Pp. ix + 108. Figs. 14. Cloth, 8½ x 5½ 4.00
Outlines of Geomorphology. By S. W. WOODRIDGE and R. S. MORGAN. Pp. xxi + 445. Figs. 272. Cloth, 6 x 9 ..... 4.50
Practical Oil Geology. 5th Ed. By D. HAGER. Pp. 455. Illus. Cloth, 6 x 9 ..... 4.00
Geology, Principles and Processes. 2nd Ed. By EMMONS, THIEL, STAUFFER and ALLISON. Pp. 447. Illus. Cloth, 6 x 9 ..... 3.75
A Descriptive Petrography of the Igneous Rocks. Vol. IV. The Feldspathoid Rocks, etc. By A. JOHANNSEN. Pp. 524. Cloth, 6¾ x 9¾ 4.50
The Examination of Fragmental Rocks. Revised Ed. By F. G. TICKELL. Pp. x + 153. Figs. 54. Cloth, 10 x 7 ..... 4.00
Fundamentals of the Petroleum Industry. By D. HAGER. Pp. 435. Illus. Cloth, 6 x 9 ..... 3.50
This Earth of Ours. By V. T. ALLEN. Pp. 364. Illus. 250. Cloth, 5½ x 8¾ 3.50
Our Amazing Earth. By C. L. FENTON. Pp. 346. Illus. 126. Cloth, 6 x 9 ..... 4.50
Applied Geophysics. By A. S. EVE and D. A. KEYS. 3rd Ed. Pp. x + 315. Figs. & Pl. Cloth, 8vo. 4.25
Vanishing Lands. By R. O. WHYTE and G. V. JACKS. Pp. 321. Illus. Cloth, 6½ x 9½ 4.00
Geology and Allied Sciences. A thesaurus and coordination of terms. Pt. I. German-English. Pp. 400. Cloth, 5⅝ x 8⅛ 7.50
Geomorphology. By A. K. LOBECK. Pp. 720. Illus. Cloth, 6 x 9 ..... 4.50
Geology and Engineering. By ROBT. F. LEGGET. Pp. 642. Illus. Cloth, 6 x 9 ..... 4.50
Petroleum Production Engineering. Oil Field Exploitation. 2nd Ed. By L. C. UREN 6.00
Earthquakes and Other Earth Movements. 2nd Ed. By JOHN MILNE and A. W. LEE. Pp. 244. Illus. 83 ..... 3.50
Mine Examination and Valuation. 2nd Ed. By C. H. BAXTER and R. D. PARKS 4.10
Internal Constitution of the Earth. Edited by B. GUTENBERG. Pp. 413. Cloth, 6¾ x 9⅜ 5.00
Geology of China. By J. S. LEE. Pp. xvi + 528. Illus. 93. Cloth, 8vo 9.00
Geology of South Africa. 2nd Ed. By ALEX L. DU TOIT. Pp. 556. Pl. 41. Figs. 68. Geol. Map. Cloth, 8vo 7.00
Strategic Mineral Supplies. By G. A. ROUSCH. Pp. 473. Cloth, 6 x 9 ..... 5.00
Applied Geophysics. 3rd Ed. By A. S. EVE and D. A. KEYES 4.25
Recent Marine Sediments. Edited by P. D. TRASK. Pp. 736. Figs. 139. Cloth, 6 x 9 ..... 5.00
The Principles of Sedimentation. By W. H. TWENHOFEL. Pp. 593. Illus. Cloth, 6 x 9 ..... 6.00
Elements of Geology. 2nd Ed. By W. J. MILLER. Pp. viii + 524. Figs. 367. Cloth 3.50
Textbook of Geology. 2nd Ed. By LONGWELL, KNOPF and FLINT. Pp. ix + 540. Figs. 340. Cloth 3.75
Textbook of Geomorphology. By G. WORCESTER. Pp. 565. Illus. Cloth 4.00
Physiography of Eastern United States. By M. FENNEMAN. Pp. 691. Illus. Cloth 6.00
Geology of N. America. Vol. I. By R. RUEDEMANN and R. BALK. Pp. xi + 643. Pl. 14. Figs. 53. Cloth, 6 x 9½ 6.50
Descriptive Petrography of the Igneous Rocks. Vol. I, Revised. By A. JOHANNSEN. Pp. xxiv + 318. Figs. 145. Cloth, 6⅝ x 9¾ 4.50
The Throne of the Gods. By A. HEIM and A. GANSSER. Pp. 233. Pl. 220. Figs. 16. Map 5.00
Mineral Industry. Vol. 47, 1938. By G. A. ROUSCH. Pp. 783. Cloth, 6 x 9 ..... 12.00
Principles of Economic Geology. 2nd Ed. By W. H. EMMONS. Pp. 518. Illus. 650. Cloth, 6 x 9. 4.00
Structural and Field Geology. By JAS. GEIKIE. 5th Ed. Revised by R. CAMPBELL and R. M. CRAIG. Pp. 305. Pl. 60. Figs. 147. Cloth, 6 x 9 ..... 6.50
Conservation in the United States. By GUSTAFSON, RIES, GUISE and HAMILTON. Pp. xi + 445. Illus. 232. Cloth, 6¾ x 9¾ 3.00
Sedimentary Petrography. 3rd Ed. By H. B. MILNER. Pp. xxiv + 666. Pl. 52. Figs. 100. Cloth 9.00
O. C. Marsh: Pioneer in Paleontology. By C. SCHUCHERT and C. M. LEVENE 5.00
Commodities in Industry. Compiled by Commodity Research Bureau. Pp. 720. Illus. 200. Buckram, 8½ x 11 ..... 7.50
Organic Reagents Used in Quantitative Inorganic Analysis. 2nd Ed. By W. PRODINGER. Trans. by S. HOLMES. Pp. 203. Cloth, 6¼ x 9¼ 5.00

Ill.
ca)
THE

2.70
5.00
1.25

1.75

3.00
5.90
9.50

1.75

0.50

3.25
3.00
3.00

1.50
6.25
6.00

3.50
6.75
2.75
4.75
3.50
5.00
1.75
5.00
4.00
5.00
9.75

4.00

4.50
4.00

3.75

4.50

4.00
3.50
3.50
4.50
4.25
4.00

7.50
4.50
4.50
6.00

3.50
4.10
5.00
9.00

7.00
5.00
4.25
5.00
6.00
3.50
3.75
4.00
6.00

6.50

4.50
5.00
2.00
4.00

6.50

3.00
9.00
5.00

7.50

5.00